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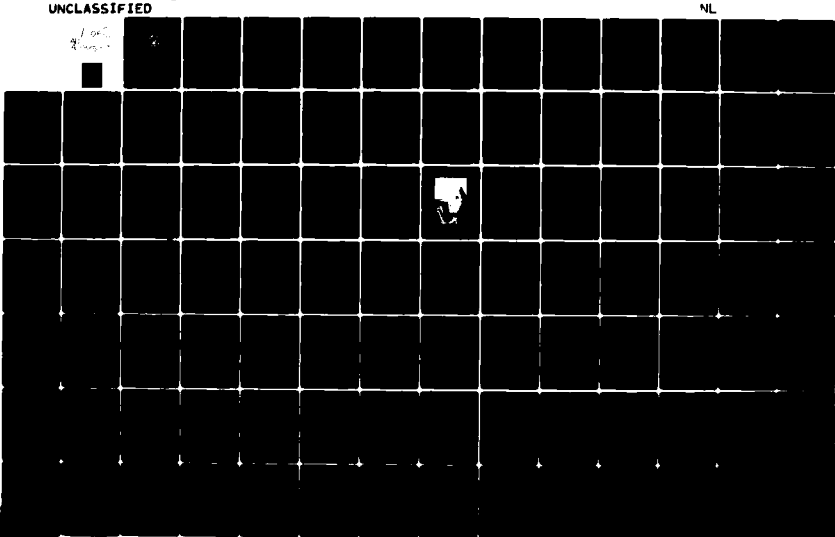

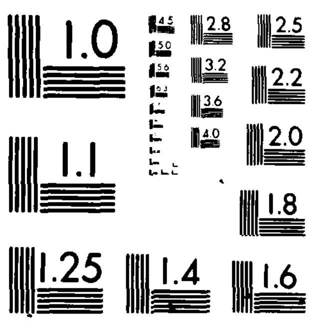

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THESIS

THE EFFECTS OF CONCURRENT
MOTOR TASKING ON PERFORMANCE
OF A VOICE RECOGNITION SYSTEM

by

John William Armstrong

September 1980

Thesis Advisor: G.K. Poock

Approved for public release; distribution unlimited

81 1 08 023

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO. AD-A093557

3. RECIPIENT'S CATALOG NUMBER

9

4. TITLE (and Subtitle)

6

The Effects of Concurrent Motor Tasking on Performance of a Voice Recognition System.

5. TYPE OF REPORT & PERIOD COVERED

Master's Thesis;
~~September 1980~~

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

10

John William Armstrong

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Naval Postgraduate School
Monterey, California 93940

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

Naval Postgraduate School
Monterey, California 93940

11

12. REPORT DATE

Sep ~~tember 1~~980

13. NUMBER OF PAGES

104

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

12

105

15. SECURITY CLASS. (of this report)

UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

VTAG
Voice Data Entry
Speech Recognition
Voice Recognition
Automatic Word Recognition
Human Factors
Task-induced Stress
Pursuit Tracker

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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S/N 0102-014-6601

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A

The Effects of Concurrent Motor Tasking on Performance of a Voice Recognition System

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Submitted in partial fulfillment of the
requirements for the degrees of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

and

MASTER OF SCIENCE IN APPLIED MATHEMATICS

from the

NAVAL POSTGRADUATE SCHOOL
September 1980

Author ____________________

Approved by: ____________________ Thesis Advisor

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ABSTRACT

This research investigated the effects of concurrent operator motor loading on performance of a voice recognition system comprised of a human operator and a discrete utterance voice recognition system. Increased concurrent operator motor workload (with respect to that experienced during training of the voice recognition system) was found to degrade system performance. Operator motor loading was manipulated using a rotary pursuit tracker. A special vocabulary was used to ensure a baseline recognition error rate to facilitate detection of factors influencing system performance. The results using the special vocabulary also indicated the performance degradations that a real world operator may encounter when using different phrases that are similar to one another in sound.

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ACKNOWLEDGEMENTS

I wish to gratefully acknowledge the guidance and encouragement of my thesis advisor, Professor G. K. Poock, and second reader, Professor T. Jayachandran.

Other Naval Postgraduate School staff members' advice and assistance were also invaluable in my program of studies. These staff members include Professor D. R. Barr, Professor R. S. Elster, Professor J. K. Hartman, Professor G. T. Howard, Commander W. F. Moroney, Ph.D., Professor D. E. Neil, Professor C. O. Wilde and Mr. P. W. Sparks.

I am also indebted to the generous students and staff members of the Naval Postgraduate School who volunteered to be subjects in my research.

Finally, I wish to thank my wife Kathy and sons, Derek and Brian; this effort would not have been possible without their love, patience and understanding.

I. BACKGROUND

A. INTRODUCTION

The use of voice to input data to machines has recently become technically and practically feasible. The range of potentially advantageous commercial and military applications of this medium appears extensive. Many applications have already been successfully tested and many others are currently being investigated; examples of each type are access control and command and control by senior officers respectively.

Commonly the operator of such a system inputs data by voice while simultaneously performing a variety of other tasks; this feature is one of the chief advantages of voice input. The operator is usually not performing these or any other tasks when he provides reference samples of his speech to the voice recognition device, i.e., when he "trains" the device to recognize his speech. However, additional tasking can induce psychological stress and task-induced stress has been shown to produce changes in human speech (Hecker and others, 1968). Consideration of the above observations raised the following question:

> Do these task-induced stresses significantly degrade performance of the voice recognition system as compared to when the system was trained and operated without simultaneous operator tasking?

Published research has not adequately investigated the potential effect of task-induced stresses on voice recognition performance. Harris, North and Owens (1978) observed a statistically significant ($p < .05$) increase in voice recognition device error rate with increased operator task load (generated with a simultaneous compensatory tracking task); however, their research was not primarily concerned with this phenomenon and their conclusions must be viewed as tentative since three of their eight subjects were deleted from the recognition error rate analysis due to lost data or because they failed to generate recognition errors. Skriver's research (1979) suggested a similar relationship between recognition error rate and operator task load on a compensatory tracking task but his observed differences in error rate were not statistically significant ($p > .10$) and his research, like that of Harris, North and Owens, was not primarily concerned with this.

The research reported here was conducted to further the studies referenced above. Specifically, it was designed to clearly answer the following questions:

Does concurrent operator motor loading significantly degrade performance of a voice recognition system as compared to when the system was trained and operated without concurrent operator motor loading?

The first chapter provides background information; it includes brief descriptions of the status of voice recognition technology and its applications, the physiology of speech and basic descriptive linguistics, speech changes associated with task-induced stress, the principles of operation of the voice recognition device used in this research, a Threshold Technology Inc. Model T600 discrete utterance voice recognition system, and a summary section. Chapter Two describes the experiment conducted. Chapter Three is a discussion of the results.

B. VOICE RECOGNITION TECHNOLOGY: STATUS AND APPLICATIONS

The many advantages of using voice to input data to machines include (Lea, 1980a; Lea, 1980b; and Lea and Shoup, 1979):

1. It frees the operator's hands and eyes and allows him more freedom of movement and orientation than other input modalities;
2. Speech is the human's fastest and most natural input modality and consequently little or no operator training is required;
3. It requires no panel space;
4. It is compatible with telephone and radio communication; and,
5. Speech is unaffected by weightlessness and less affected by high levels of acceleration and mechanical

constraint than are conventional mechanical modes of machine input, such as pushing buttons, turning knobs, etc.

Several disadvantages to using voice to input data to machines also exist but it appears that they can be overcome (Lea, 1980a; Lea, 1980b; and Lea and Shoup, 1979). The disadvantages include:

1. Speaker variability, due to sex, dialect, experience, etc., is considerable;
2. Speech communication is not private;
3. Speech communication is subject to environmental noise and distortions; and,
4. Using voice to enter data can be costly and restricted.

Work in voice recognition by machine commenced in 1952, several years after the introduction of the sound spectrograph. Since then, dramatic advances in electronic computer technology have permitted corresponding advances in voice recognition technology and it has become evident that a whole continuum of types of voice recognition devices are feasible. At one end of the scale are speaker-dependent devices which recognize isolated words (words separated by pauses and spoken by the person who "trained" the device). At the other end of the scale are speaker-independent devices which would recognize task-independent continuous speech (continuous speech on any topic spoken by anyone). Today several speaker-dependent devices, which recognize isolated words from vocabularies of

up to about 900 words with accuracies in some cases exceeding 99%, are commercially available. Some military and commercial applications of these available devices which have been investigated or are actually operative are:

1. Data entry in cartography (Scott, 1978);
2. Training air traffic controllers (Grady and Hicklin, 1976) and use in actual air traffic control situations (Connolly, 1979);
3. Command and control by senior officers (Poock, 1980);
4. Spotting key words in monitored conversations (Beek, Neuberg and Hodge, 1977);
5. Access control (Doddington, 1980);
6. Quality control and inspection (Interstate Electronics Corporation brochure, 1979); and,
7. Voice actuated devices for the handicapped.

Other applications and more detail of the history and types of voice recognizers are given in Lea (1980a), Lea (1980b) and Lea and Shoup (1979).

Current research is directed at lowering the cost of devices like those currently available, making them more usable over communication links such as telephone, and making accurate and versatile continuous speech recognizers available commercially. Lea (1980a) predicts a "rapidly expanding market, and a growing variety of applications" for voice recognition devices.

C. PHYSIOLOGY OF SPEECH PRODUCTION AND DESCRIPTIVE LINGUISTICS

This section was included to define terms used in following sections and to emphasize the complexity of speech creation. The definitions given were taken from Flanagan (1972) and Lea (1980a).

Figure 1 shows some of the basic physiological elements used in the creation of human speech. These elements were primarily designed for chewing, swallowing and breathing and have evolved the secondary voluntary speech function (Greene 1964).

The energy source for speech creation is air exhaled from the lungs. This air flow may be made to cause the vocal cords to vibrate, as follows. Consider the vocal cords initially closed so that no path exists for air to exit the lungs. As the diaphragm forming the base of the lung cavity is raised the air pressure below the cords (subglottal pressure) increases until finally the cords are forced apart. As the air flow through the resulting opening (glottis) increases, the local pressure is reduced according to the Bernoulli relation, and a force acts to return the cords to the closed or proximate position. As the cords are again drawn together the air flow is decreased and the local pressure approaches the subglottal value. The cycle then repeats itself. This results in a cyclic vibration called phonation and a series of pulses of air (called glottal pulses) to excite the acoustic system above the vocal cords (supraglottal system).

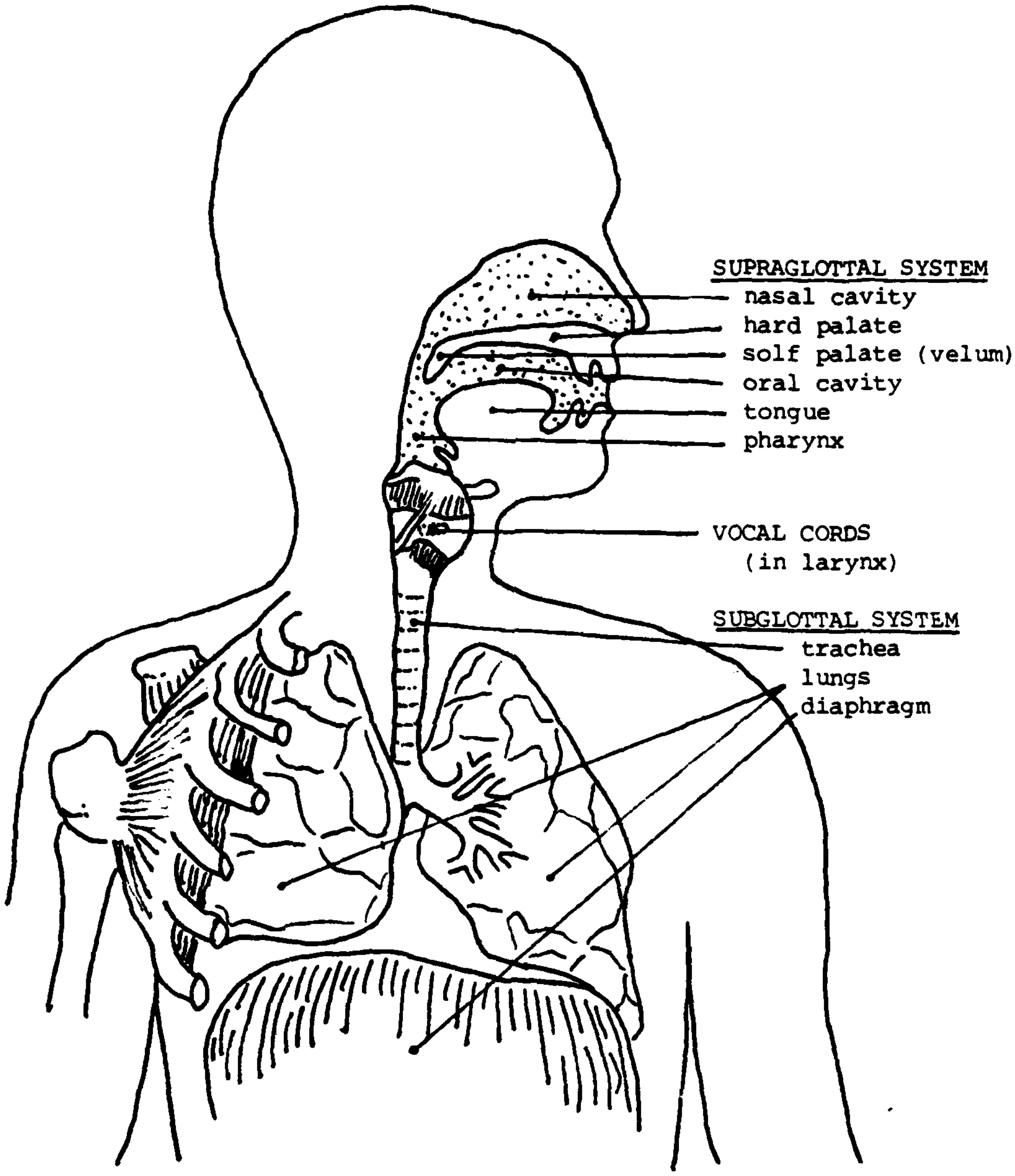


FIGURE 1. PHYSIOLOGICAL ELEMENTS USED IN THE CREATION OF HUMAN SPEECH

(Adapted from Lea, 1980a)

Sounds for which the vocal cords are periodically vibrating are called voiced sounds; the frequency of vibration of the cords is called the fundamental frequency of voicing, F_o. Sounds for which the vocal cords are not periodically vibrating are called unvoiced or voiceless sounds.

Another means of producing audible sound is to cause the airflow to pass through a narrow constriction at some point which creates turbulence in the flow; this is called frication. The sound produced will depend on the point and manner of construction. For example, the tongue can be placed against the upper teeth or against the roof of the mouth (hard and soft palates) at various locations.

Resonators, or adjustable cavities such as the nasal cavity, oral cavity, pharynx, and trachea, serve to accent various frequencies of the sound; peaks in the frequency spectrum of the sound thus produced are called natural resonances or formants of the speech signal. The first formant, F_1, usually ranges from 200 to 1000 Hz, the second formant, F_2, from 750 to 2700 Hz and the third formant, F_3, above 2200 Hz. Other formants may exist but are usually weak and of lesser importance in the analysis of speech signals than the first three.

A language consists of a finite number of distinguishable and mutually exclusive basic sound elements called phenemes. Phenemes have the property that if one replaces another in an utterance, the meaning of the utterance is

changed. The permissable variations of any particular phoneme are called allophones; two different phonemes may not have the same allophone.

Each language has its own set of phonemes and features of speech which are phonemically distinct in one language may not be phonemic in another. English has 46 different phonemes (Gleason, 1965) divided into two main groups, vowels and consonants.

The vowel sounds of English are normally produced exclusively by voiced excitation of the vocal tract. In normal articulation the tract is maintained in a relatively stable configuration during most of the sound; the particular vowel uttered depends on the position of the tongue hump, which is often the place of greatest constriction, and the degree of the constriction. The vowels are also characterized by negligible nasal coupling and by radiation only from the mouth.

The consonants are those sounds which are not exclusively voiced and mouth-radiated from relatively stable tract configurations. In general they are characterized by greater tract constrictions than the vowels. Continuants are those consonants which do not require vocal motion and thus may be uttered as sustained sounds as the vowels may be.

Fricative consonants (or fricatives) are produced from noise generated by turbulent air flow at some point of constriction of the vocal tract. Common constrictions for

producing fricatives are those formed by the tongue behind the teeth (dental), the upper teeth on the lower lip (labiodental), the tongue to the gum ridge (alveolar), the tongue against the hard or soft palate (palatal or velar, respectively), and the constricted and fixed vocal cords (glottal). Fricatives are continuants and normally radiated from the mouth. They can be either voiced (if the vocal cords operate in conjunction with the noise source) or unvoiced (if the vocal cords do not operate in conjunction with the noise source).

Stop consonants require vocal tract dynamics in their creation. A complete closure of the tract is formed (labial, alveolar, palatal or velar) and pressure is built up below this closure. The stop consonant is uttered when this pressure is suddenly released and may be either voiced or unvoiced.

Nasal consonants (or nasals) are continuants and voiced and most of the sound is radiated from the nostrils. Just how the oral cavity is closed (by the lips or by the tongue at the gum ridge or hard or soft palate) influences the oral cavity resonance and hence the sound radiated.

Glides and semivowels are two groups of voiced consonants which greatly resemble vowels; they are characterized by no effective nasal coupling and sound radiation from the mouth. The glides are dynamic sounds which precede a vowel and exhibit movement towards the vowel. The semivowels are continuants in which the oral channel is more constricted

than in most vowels and the tip of the tongue is not down.

Dipthongs and affricates are combinations of vowels and stop-fricatives respectively; both involve vocal tract motion. Diagrams showing the location of the major physiological elements during creation of each phoneme may be found in most texts on speech or linguistics (for example, Flanagan (1972) and Gleason (1965)).

Two speech utterances comprised of exactly the same two sequences of allophones may still appear to be very different. This may be due to differences in the stress levels on various syllables and their distribution throughout the utterances, differences in the intonation or systematic variation of pitch throughout the utterances, or differences in the rhythm and pauses used. These features of speech that go beyond the phonemic features are called suprasegmentals or prosodic features.

Speech is not simply the result of many isolated movements. It is an extremely complex voluntary function involving the well-coordinated and delicate movements of many organs. The next section will describe some of the changes in this complex function that are associated with task-induced stress.

D. SPEECH CHANGES ASSOCIATED WITH TASK-INDUCED STRESS

Psychological stress, however induced, produces a variety of changes in human speech; these changes vary considerably

from person to person. Many researchers have tried, with varying success because of inter-subject variability, to use knowledge of these characteristic changes to estimate subject stress through analysis of his voice communication. For example, Kuroda and others (1976) discussed a method for determining pilot stress and Khachaturyants and Grimak (1972) and Kuznetsov and Lapayev (1975) discussed determination of cosmonauts' stress.

One of the most consistent and extensively studied changes in speech which accompany increased stress is a rise in the fundamental frequency. Analysis of pilots' radio transmissions during serious flight difficulties compared with transmissions made before such difficulties were encountered has shown this relationship between stress and fundamental frequency (Williams and Stevens, 1969). Various researchers have attempted to use this relationship to determine when subjects were lying and when they were telling the truth (for example, Streeter and others, 1977); these attempts have usually been only partially successful because the relationship did not hold for all subjects. Hauser (1975), studying the use of fundamental frequency variations to identify stress arising in psychological counselling, found that both higher levels and increased variation of fundamental frequency commonly characterized stressful speech.

Attenuation of an 8 to 14 Hz microtremor in the speech signal is another extensively studied change which is said

to be associated with psychological stress (Smith, 1977). A device called the Psychological Stress Evaluator (PSE) is commonly used to detect and analyze these microtremors. The PSE is probably best known for its use in lie-detection situations, although the appropriateness of this has been questioned because of several serious methodological problems (Brenner and Branscomb, 1979). Schifflet and Loikith (1980) recently successfully used the PSE with an automated scoring technique to detect stress in the speech of subjects performing a four-choice information processing task at different rates. Schifflet and Loikith appear optimistic that their procedure provides an objective, reliable, sensitive and non-obtrusive measure of stress that can be used in the assessment of operator workload in vocal communication systems.

The paper by Hecker and others (1968) is one of the few articles specifically addressing speech changes associated with task-induced stress. The changes they observed appear to this author similar at least in type to the changes observed in other research where the stress was not task-induced. Their subjects were required to read six gauges, sum the values, orally announce the sum and read a short phrase. Stress was induced by progressively decreasing the illumination period of the gauges. Their results indicate

that task-induced stress produced several characteristic changes in the speech signals. Most of these changes were attributable to modifications in the amplitude, frequency and detailed waveform of the glottal pulses. Other changes resulted from differences in articulation. Although the manifestations of stress varied considerably from subject to subject, some consistent effects were exhibited by most subjects. Some of the observed differences between speech in the control and stress condition were:

1. Differences in volume, in both directions;
2. Overall differences in fundamental frequency, in both directions;
3. Differences in the time contour of the fundamental frequency (for example, in one condition (stress or control) the fundamental frequency tended to increase from beginning to end of an utterance but in the other condition the fundamental frequency tended to decrease from beginning to end of the same utterance);
4. Differences in the precision of articulation (for example, some subjects slurred syllables together or omitted some speech sounds altogether when stressed);
5. Differences in the amount of high frequency energy in the glottal pulses and in voiceless consonants;
6. Differences in monotonicity of the speech (some of the subjects tended to speak in more of a monotone when they were stressed); and,

7. Differences in the regularity of glottal vibration (stressed speech tended to have more irregularity in the pattern of glottal vibration, referred to as voicing irregularity).

Most of the speech changes described in this section were detected by sophisticated electronic equipment. However, at least some changes were apparent to human listeners as several of the studies referenced found that independent human listeners could often correctly identify, with better than chance accuracies, which speech was stressed and which was not. This observation is consistent with the author's, and probably most readers', personal experience; the author can recall numerous occasions on which the speech of some temporarily frustrated, excited or frightened acquaintance distinctly changed in some manner.

E. PRINCIPLES OF OPERATION OF THE THRESHOLD TECHNOLOGY INC. MODEL T600 DISCRETE UTTERANCE VOICE RECOGNITION SYSTEM

The speech recognition system used in this research was a Threshold Technology Inc. Model T600 discrete utterance voice recognition system, a speaker-dependent isolated utterance recognizer. The T600 could be trained to recognize any continuously spoken utterance (i.e., not including pauses) of between .1 second and two seconds duration. An utterance could thus be a single word, a continuous string of several words, or a continuous string of nonsense sounds not necessarily

comprising any known word or words. The T600 used in this research had several added memory modules which allowed use of vocabularies of up to 256 utterances. Utterances spoken for recognition by the T600 had to be separated by pauses of at least .1 second duration or else the T600 "connected" the utterances and tried to recognize the "connected" utterances as one utterance.

An utterance spoken into the special T600 noise-cancelling microphone was processed as follows. The signal from the microphone was passed through 19 bandpass filters spanning the speech spectrum; the filters were spaced non-linearly to minimize the number required. A spectral shape detector then calculated rate of change of energy level with respect to frequency information to describe the overall signal spectral shape. The spectral shape and its changes over time were continuously calculated and these measurements were processed to determine presence or absence of each of 32 acoustic features; this binary feature information was produced every two milliseconds. The features were of two main types. About half of them were related to the relative energy content of particular spectral bands. The other half resulted from logical and analog operations on the short-term power spectrum and most were attempts to automatically detect phonemic information.

When the end of the utterance was detected, by means of the pause which separated consecutive utterances, the duration

of the utterance was divided into 16 time segments and the features were reconstructed into a normalized time base. This process resulted in a 512 bit - 32 binary features by 16 time segments - description of the utterance.

During the training of the T600 the subject repeated each utterance of the vocabulary ten times; ideally the ten repetitions of an utterance were representative of the variety of ways the subject normally said the utterance. The T600 extracted a 512 bit feature matrix for each version of each utterance. The ten matrices for each utterance were then combined to produce a single reference matrix for each utterance; an element a_{ij} of the reference matrix for an utterance indicated presence of feature i at time segment j only if feature i was present at time segment j in a minimum number of the original ten matrices for that utterance. (Threshold Technology has not disclosed the value of this minimum number.)

When an utterance was spoken for recognition by the T600 a 512 bit descriptive matrix was calculated and weighted correlations between this matrix and each of the reference matrices describing the vocabulary utterances were calculated. The vocabulary utterance which resulted in the largest correlation exceeding some preset threshold value was then selected as the utterance which the T600 "thought" was spoken. If no correlation exceeded this preset threshold value the T600 emitted a "beep" sound which signalled the operator to try again.

The T600 functioned similarly to the older Threshold Technology Inc. VIP 100 which was described in some detail by Porter and others (1977) and Martin and Grunza (1974). Recognition accuracies obtained with the VIP 100 have often been better than 99% as, for example, in the studies by Martin and Grunza (1974), Scott (1975) and Scott (1978).

Several other discrete utterance recognizers operate in a similar manner to the T600; often different descriptive features of the speech are extracted and/or a different number of time segments used. Other recognizers operate differently. Lea (1980a) and Lea (1980b) provide summaries of available detail on commercially available recognizers and on other recognizers still in the developmental or prototype stages.

F. SUMMARY

The previous pages have briefly described the physiology of speech, various features which characterize the acoustic speech signal, changes in these features associated with task-induced stress, and how the successful operation of a particular speech recognition device depends on extraction of some of these descriptive features from the speech signal over time and comparison of the resulting representation of the speech with previously stored reference representations of the operating vocabulary. The author hypothesizes that if operator tasking is significantly different during training and operation

of the recognizer, as if often the case, then the operator's speech will not be the same during training as during operation and consequently performance of the recognition system will be less than optimal. The fact that the changes in speech associated with task-induced stress may be different in nature and/or direction for different operators, which has limited the success of determining subject stress through analysis of his speech, does not obviate this argument. Certainly different changes and different directions of change may cause different degrees of decrement and the degree of decrement may also be different for different recognition devices because of differences in the descriptive features extracted and/or algorithms used; nevertheless, the decrement should occur to some degree with all recognition devices and with all operators whose speech changes in some manner.

The objective of this research was to begin to investigate this expected decrement in recognition system performance. In particular, this research attempted to clearly answer the following question, which was posed at the beginning of this chapter:

> Does concurrent operator motor loading significantly degrade performance of a voice recognition system as compared to when the system was trained and operated without concurrent operator motor loading?

It is emphasized that this research was an investigation into a phenomenon which should be common to all voice recognition systems.

II. DESCRIPTION OF THE EXPERIMENT

A. OBJECTIVE

The objective of this experiment was to determine if concurrent operator motor workload affected the performance of a voice recognition system comprised of a human operator and a discrete utterance voice recognition device. A special vocabulary was used to ensure a baseline error rate with which to compare various motor loading levels. As such, it was expected that absolute error rates would be higher than those normally realized in real world operations.

B. SUBJECTS

Twenty-four subjects participated on a volunteer basis with no monetary or other incentive. Twenty of the subjects were male military students at the Naval Postgraduate School (NPS), three were male, military staff members at NPS, and one was a female civilian employee of NPS. The military officers represented the United States Navy, Army, Marine Corps and Coast Guard and their ranks ranged from Lieutenant to Lieutenant-Commander and from Captain to Major inclusive. All subjects were between the ages of 26 and 38 inclusive.

None of the subjects had any previous experience on the voice recognition system used in the experiment. Only three of the subjects - numbers 1, 6 and 13 - had any experience - two hours each - on pursuit tracking devices, the type of

device used to create operator motor loading.

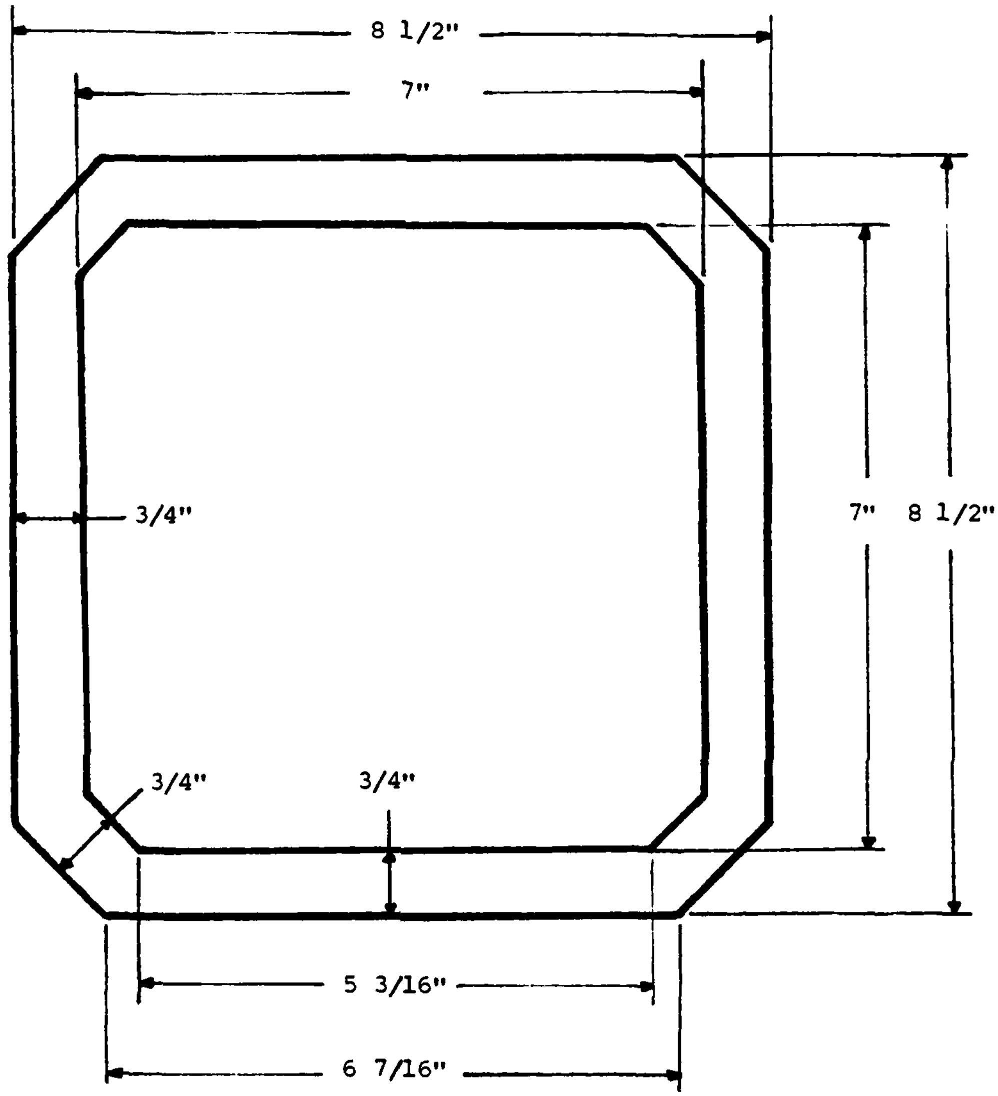
C. EQUIPMENT USED

1. Pursuit Tracker

A Lafayette Instrument Co. Model 2203E Photoelectric Pursuit Tracker was used to induce operator motor loading. The tracker was positioned on a table in the booth so that the pursuit surface was 34.25 inches above the floor. Subjects stood while performing the tracking task and were required to track an approximately .75 inch square light target with a 13.06 inch long wand. The target travelled clockwise at a constant 40 rpm around both of two paths used. One path was circular with outer diameter 12 inches; the other, detailed in figure 2, was square-like. Figure 3 is a photograph of the tracker in the booth (described later). A camera exposure time of 1.5 seconds was used for the photograph so that the target would travel completely around and illuminate the whole path.

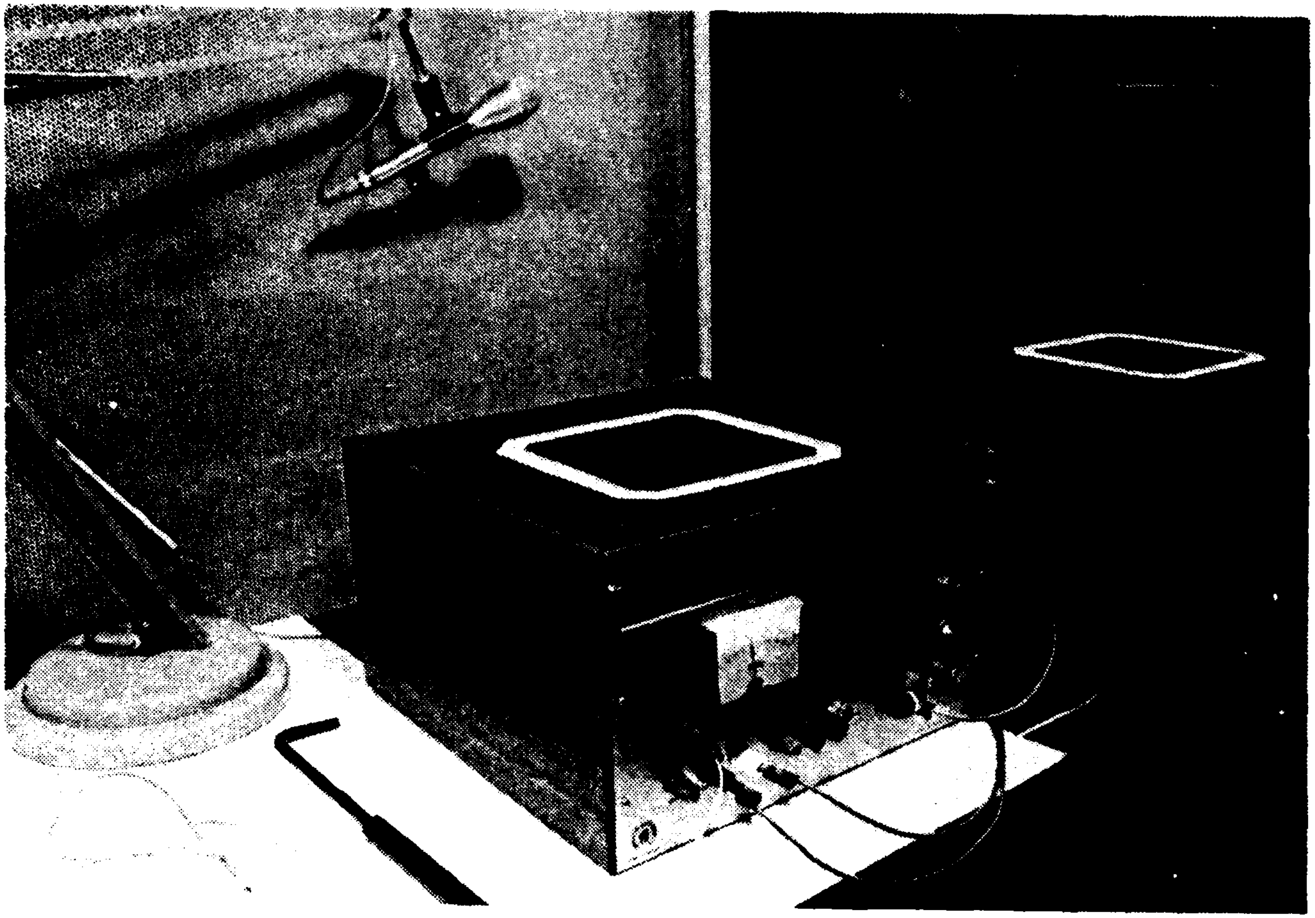
Time on target (TOT), the performance score for the tracking tasks, was recorded using a Lafayette Instrument Co. CraLab Model 172 timer and task duration was controlled using a Lafayette Instrument Co. Model 54014 Stop Clock. Both of these devices were located outside of the booth at the experimenter control station.

Harris (1978) reviewed research reported from 1967 to 1977 inclusive on concurrent verbal and tracking tasks. He



All dimensions are given in inches.

FIGURE 2. SQUARE-LIKE TRACKER PATH



Booth microphone

Tracker wand

Tracker

FIGURE 3. TRACKER ON TABLE IN BOOTH

concluded that "it is clear that performance of some verbal tasks interferes with simultaneous performance of some tracking (control) tasks" and that "it is probable that certain parameters of the control task will be important determinants of any decrement in performance observed during simultaneous verbal information processing." Subsequent research by Harris, North and Owens (1978) involving inputting data with a voice recognition device and compensatory tracking found decrements in performance of both of these tasks when performed simultaneously versus when they were performed separately. For example, they found that when the voice input and tracking tasks were performed concurrently recognition error rate was approximately 55% greater and tracking RMS error approximately 30% greater than when these tasks were performed separately.

2. Voice Recognition System and Choice of Vocabulary

A Threshold Technology Inc. Model T600 discrete utterance voice recognition system (which will hereafter be referred to as the T600) was used as the equipment component of the combined equipment plus human operator voice recognition system. A description of the operation and capabilities of this equipment was provided in Chapter One.

The vocabulary used in this experiment consisted of 50 different utterances. Thirty were single words selected by the experimenter from the Listener's Answer Sheets of the Modified Rhyme Test, one of the four test types which have been commonly used in measuring intelligibility in speech

communication (Kryter, 1972). Sixteen of these 30 words were eight pairs of rhyming words which, within each pair, differed only with respect to initial consonant - for example, "beat" and "peat". The other 14 words were seven pairs of non-rhyming but similar words which, within each pair, differed only with respect to final consonant - for example, "sap" and "sat". The other 20 utterances were chosen by the experimenter from single words commonly used in Command and Control environments; they were chosen to be more easily distinguished from each other and from the other 30 words of the vocabulary.

All words of the vocabulary were one or two syllables in length. Short words were deliberately selected to facilitate generation of as many T600 word recognition attempts as possible in the limited time that each volunteer subject was available. The vocabulary is listed by word type in Appendix A. A listing in the order in which the words were trained is attached to the written instructions initially given to subjects and is contained in Appendix C.

This particular vocabulary was chosen to increase the likelihood of recognition errors by the T600 for the following reasons. (T600 recognition errors (RE's) are operationally defined in the Dependent Variables section of this chapter.) Recognition accuracy with older Threshold Technology Inc. voice recognition equipment similar to the T600 and using more normal vocabularies (i.e., comprised entirely of more easily distinguished words) has often been better than 99%, as for

example, in the studies by Martin and Grunza (1974), Scott (1975) and Scott (1978). This level of accuracy would produce an average of about one (or less) RE's per 100 spoken utterances. It was anticipated that if operator motor loading did affect recognition accuracy then the effect would be relatively small and, due to the discrete nature of RE's, would probably not be easily distinguishable if only one RE per 100 utterances were being observed - for example, a 20% increase in RE's would probably not be great enough to produce a sufficient number of increased RE observations to be statistically distinguishable from inherent random variation. However, if a vocabulary could be chosen to produce approximately ten RE's per 100 utterances a 20% increase in RE's should be more easily distinguishable as this would result in an average observation of 12 RE's per hundred utterances.

An alternative method of detecting a small expected change in recognition accuracy would be to increase the number of utterances spoken by the subjects. This was not considered feasible here because of the greatly increased time which would be required of each of the volunteer subjects; the experimental design used required between 1.5 and two hours per subject. For this reason, the former method, special vocabulary, was used.

3. Arrangement of Equipment Used

Figure 4 illustrates the functional relationships among the various experimental devices used in the experiment.

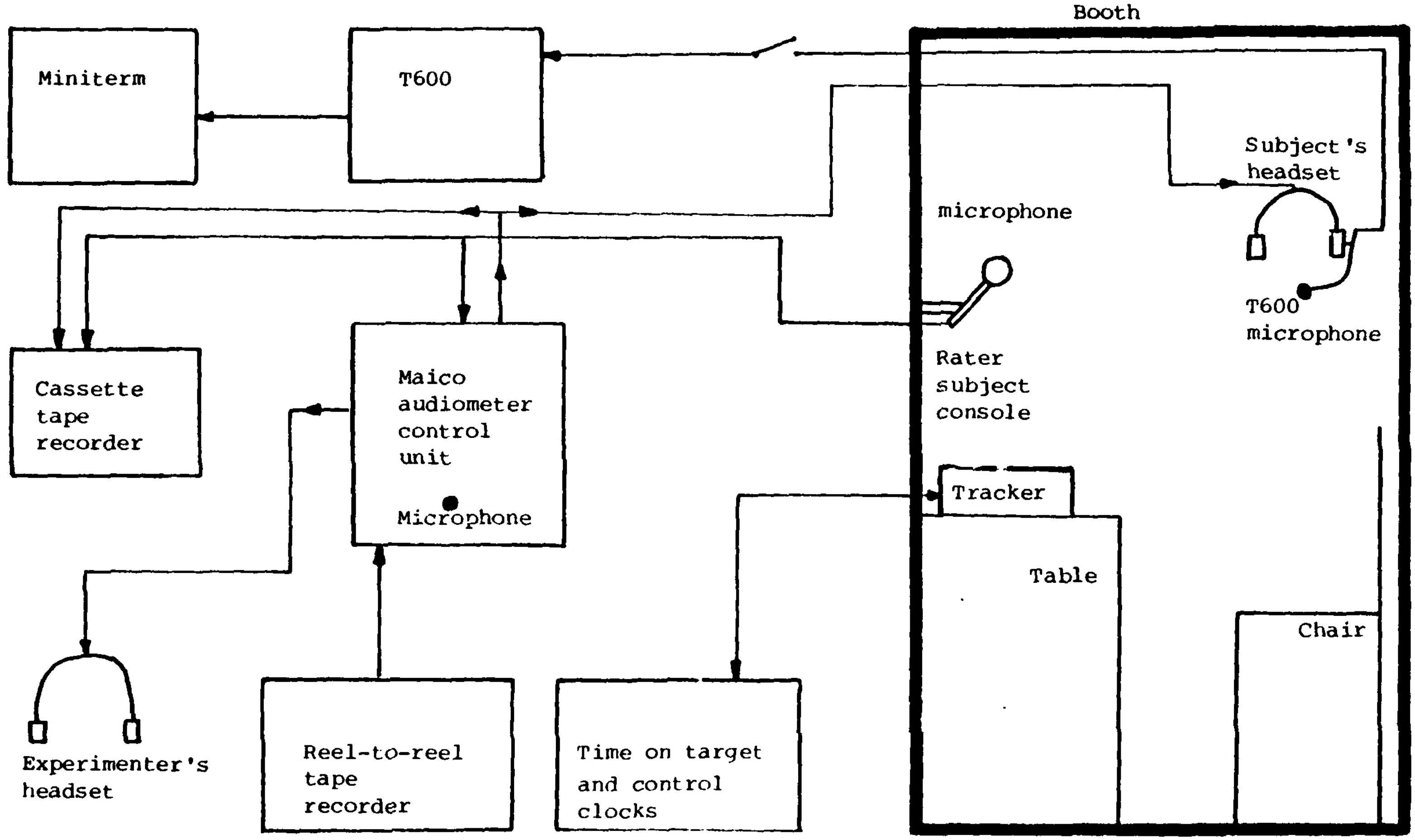


FIGURE 4. BLOCK DIAGRAM OF EXPERIMENTAL CONTROL SYSTEM

The subjects were seated (except while tracking) one at a time in an Industrial Acoustics Co. Inc. Controlled Acoustic Environments booth. The tracker was on a table in front of the subject.

A Maico Model MA-24B Dual Channel Research and Diagnostic Audiometer and headsets were used to provide oral communication between the subject and the experimenter. The experimenter could speak to the subject by depressing a "talk-over" switch. Another microphone, placed in the booth, was live at all times and permitted the experimenter to hear what was happening in the booth - in particular, what the subject said. A Sony model TC 124 cassette tape recorder was connected to permit simultaneous recording of the signals detected by the booth microphone and the signals that the subject received over his headset.

The special T600 system noise-cancelling microphone was mounted on the subject's headset and connected only to the T600. The microphone ON/OFF switch was located outside of the booth.

A Computer Devices Inc. Model 1203 Miniterm portable terminal was connected to the T600 system in such a manner that when the T600 recognized an utterance the output string for that utterance was typed at the terminal. The T600 was programmed so that the ASCII output stream associated with each utterance of the vocabulary was simply the letters spelling the utterance followed by a carriage return and a line

feed; thus, for example, if in the recognition mode the T600 "thought" that a subject said "attack", the word "attack" was displayed on the CRT on a separate line and printed at the terminal, also on a separate line. This provided the experimenter with a paper printout of T600 recognition activity which, with the correct utterances recorded on the cassette tape recorder, permitted thorough analysis of the data. Accurate, manual, real-time analysis by the experimenter using only the T600 CRT was infeasible primarily because of the rate at which the T600 was required to process signals for recognition - one word every three seconds.

An Akai model 4000DS Mk II reel-to-reel tape recorder was connected to the Maico Audiometer and used to present stimuli to the subject.

D. EXPERIMENTAL PROCEDURE

Subjects were tested one at a time during normal working hours. They were first required to complete the Subject Data Form (Appendix B) and then read two pages of written instructions (Appendix C) which briefly introduced the experiment and provided general guidelines on inputting voice data to the T600. Remaining instructions to the subject were given orally by the experimenter who closely followed the aide-memoire shown in Appendix D.

Subjects were next given a brief demonstration of the operation of the T600. For this stage the T600 microphone

and the headset on which it was mounted were removed from the booth and the microphone was reconnected outside of the booth so that the subject could immediately see what happened when speech signals were input to the T600. The importance of the guidelines which the subject had just read were demonstrated during this stage and the subject was allowed to familiarize himself with the T600 for about five minutes.

The T600 microphone and the headset on which it was mounted were then reconnected inside the booth. The 50 word vocabulary was then trained one word at a time. The experimenter had all of the T600 controls outside of the booth and closely controlled the training process, requiring the subject to retrain words as necessary - for example, if a word was initially trained monotonously. The T600 was next put in the recognition mode and recognition of each word of the vocabulary was checked. The subjects repeated each word of the vocabulary three times. Those words which were not recognized correctly at least two of the three times were immediately retrained, then rechecked and retrained as necessary. If either word of a rhyme or non-rhyme but similar word type pair required retraining both words of the pair were subsequently rechecked for recognition and retrained and rechecked as necessary before continuing.

The subject next received, via his headset, a 2.5 minute tape recording of the 50 words of the vocabulary arranged in

random order and presented at a constant rate of one word every three seconds. The subject was instructed to repeat the words one at a time for recognition by the T600. He was advised to try to repeat each word and to guess with a word in the vocabulary if he was uncertain.

Next the subject was briefed on the two tracking tasks that he would be performing - circular tracking and square-like tracking. He was advised that his tracking scores would be time on target. He was then given a 2.5 minute practice on the circular tracking task.

The subject was next given a combined 2.5 minute circular tracking and word repetition task for recognition practice. The subject was played the same 2.5 minute tape recording that he had heard earlier and was instructed as before to repeat the words one at a time for recognition by the T600. He was advised that word recognition was the higher priority task but that he was to simultaneously perform the tracking task as well as he could with whatever capabilities he had remaining after attending to the priority task. The subject was also reminded to be sure to repeat each of the taped words and to guess with a word in the vocabulary if he was uncertain.

The subject was then exposed to the three experimental conditions corresponding to the three operator motor loading conditions - no tracking task (NTT), circular tracking task (CTT), and square-like tracking task (STT). These were designed to create different levels of operator motor loading.

Each condition lasted five minutes and each of the 24 subjects received the three conditions in a different order (see Appendix E).

During condition NTT the subject was required only to repeat two different consecutive random orderings of the words of the vocabulary; these were presented to him over his headset as during practice. The first time through the vocabulary in any condition was referred to as the first half of the trial; the second time was referred to as the second half of the trial. he first word of the second half followed the last word of the first half with the same spacing used within the two halves; the subject received no cues that he was halfway through the trial. In each of the conditions CTT and STT the subject was similarly required to repeat random orderings of the vocabulary (two different orderings for each condition as in condition NTT - all random orderings used are shown in Appendix F); however, he was also required to perform simultaneously the appropriate tracking task. He was reminded that the reception of words for recognition by the T600 was the higher priority task and to guess with a word from the vocabulary if he was uncertain, as during the combined practice. (The purpose of this instruction was to ensure that the T600 received the same, or at least nearly the same, utterances for recognition during each trial half and thus provide a common basis for comparison of T600 recognition errors.) By monitoring the T600 CRT display and time on target timer, listening

to booth activity via the booth microphone, and post-experiment questioning of subjects, the experimenter ensured that subjects adhered to the instructions that they had been given.

Immediately after a subject completed each condition, and before he was allowed to leave the booth, he was instructed to complete the "Feeling Tone Checklist" shown in Appendix G in accordance with the instructions also shown in Appendix G. This checklist, developed by Pearson and Byars (1956), was administered to assess possible differential subjective fatigue after each of the three different motor loading conditions.

During the experimental conditions subjects were not given feedback on their tracking performance. During the practice sessions the only feedback given to subjects regarding T600 recognition of their speech was the knowledge of which words required retraining; no feedback regarding T600 recognition performance was given to subjects during the experimental conditions. Those subjects who indicated interest on their "Subject Data Sheets" were individually briefed on their tracking performance, T600 recognition of their speech and the hypotheses being tested immediately after they completed the last experimental condition.

Subjects were allowed to take short rest breaks as they wished during the training and practice sessions and before each of the three experimental conditions. A drinking fountain was located nearby for any subjects who became thirsty or whose throats became dry.

E. DEPENDENT VARIABLES

The following were calculated for each half of each trial:

1. T600 recognition errors (RE's)
2. Subject verbal errors.

In this experiment a T600 recognition error was operationally defined to be a failure of the T600 to recognize correctly any vocabulary word which a subject said; this included both incorrect recognition (for example, the subject said "beat" and the T600 "thought" he said "peat") and rejection (for example, the subject said "dip" and the T600 failed to recognize it and emitted a "beep" sound). This definition is different from most definitions of recognition error in the voice recognition literature which do not include rejections - for example, Martin and Grunza (1974). The operational definition used in this experiment was considered more consistent with the aim of this research - i.e., to answer the question: Would increased concurrent operator motor workload (with respect to that experienced during training of the recognition device) result in changes in his speech which would in turn result in degraded performance of the voice recognition system? It was believed that if the T600 rejected "dip" when said by a subject under condition STT, but not when said by the same subject under condition NTT, this suggested changes in system performance as a result of changes in the subject's speech and accordingly should be recorded and analyzed.

A subject verbal error was defined as a failure of the subject to repeat correctly the presented word. This failure could be either a failure to respond (omission) or responding with a non-vocabulary word or the wrong vocabulary word (commission).

Tracker time on target scores were recorded at the end of conditions CTT and STT.

F. HYPOTHESES

The following hypotheses were to be tested.

1. <u>Hypotheses Regarding T600 Performance</u>

   a. H_o: The different levels of operator motor loading would not have different effects on T600 recognition error rate.

      H_1: H_o false.

      It was expected that increased operator loading would result in increased recognition error rate (RER), i.e., RER(NTT) < RER(CTT) < RER(STT)

   b. H_o: The two trial halves would not have different effects on T600 recognition error rate.

      H_1: H_o false.

2. <u>Hypotheses Regarding Subject Performance</u>

   a. H_o: The different levels of operator motor loading would not have different effects on subject verbal error rate.

H_1: H_o false.

It was expected that increased operator loading would result in increased subject verbal error rate (VER), i.e., VER(NTT) < VER(CTT) < VER(STT)

(This hypothesis was suggested by the research of Johnston (1975) who observed a significant detrimental effect of a simultaneous compensatory tracking task on speech intelligibility in noise.)

b. H_o: The two trial halves would not have different effects on subject verbal error rate.

H_1: H_o false.

c. H_o: Time on target for the Circular Tracking Task would equal time on target for the Square Tracking Task.

H_1: H_o false.

It was expected that time on target for the Square Tracking Task would be less because in this task the constant 40 rpm angular velocity caused the target to move at a constantly changing speed whereas in the Circular Tracking Task the constant angular velocity resulted in a constant target speed.

d. H_o: Subject subjective fatigue (as measured by the "Feeling Tone Checklist" of Pearson and Byars, 1956) would be the same for the four operator motor loading conditions.

H_1: H_o false.

It was expected that increased operator loading would result in increased subjective fatigue (SF), i.e., SF(NTT) < SF(CTT) < SF(STT)

Tracker performance was not recorded at the end of the first half of trials and hypotheses regarding tracker performance versus trial half were not devised. (A test of such hypotheses would probably have shown tracker performance to be lower in the second half of trials than in the first half, due to subject fatigue.)

G. EXPERIMENTAL DESIGN

A conceptual design for the experiment is shown in figure 5. This is a three factor factorial design.

The three experimental conditions could be presented in six (three factorial) possible orders. Each order was used with four subjects. Subject to this restriction the order of presentation of the three conditions to any particular subject was assigned randomly.

Subject verbal error rate and T600 recognition error rate data were expected to be inherently Binomial in nature. In the case of subject verbal errors, the values of p, the

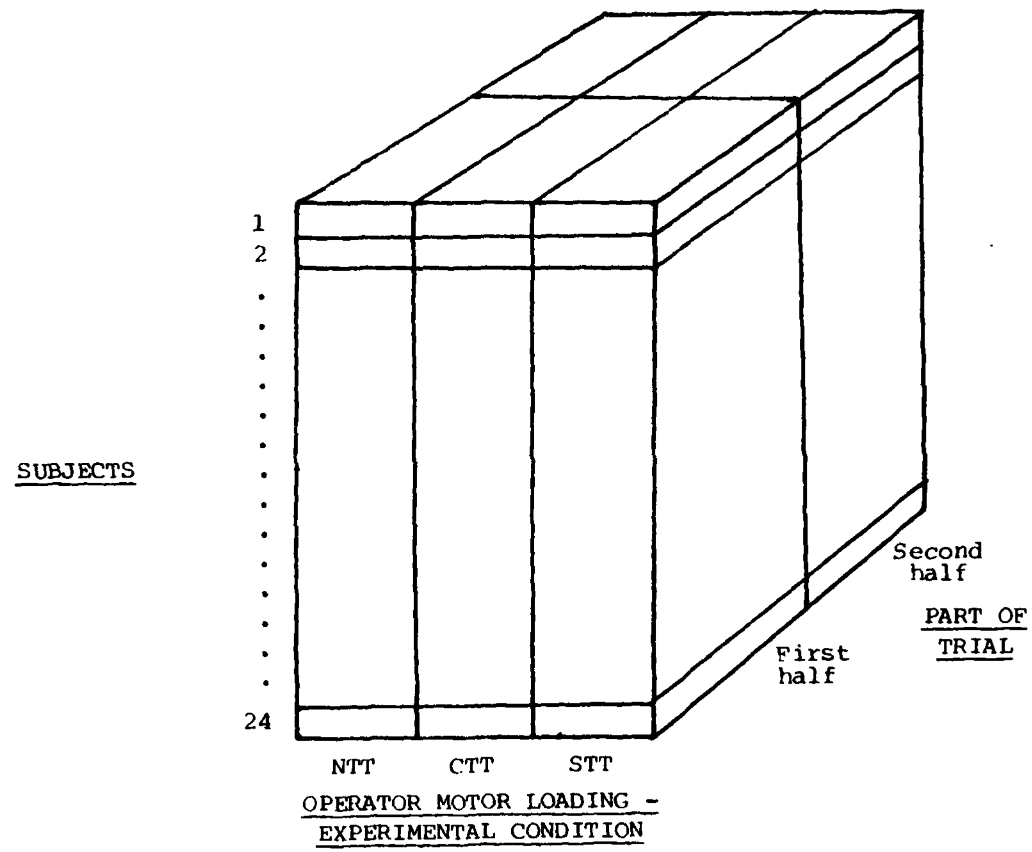


FIGURE 5. CONCEPTUAL DESIGN OF THE EXPERIMENT

probabilities of a subject verbal error, or equivalently, subject verbal error rates, were expected to be small. Because of this and because the values of n, number of words to be spoken, were relatively large, it was concluded that the distributions of subject verbal errors could be approximated by Poisson distributions and statistical methods based on the Poisson distribution were selected to test subject verbal error rate hypotheses.

In the case of T600 recognition error rates, the values of p, probabilities of a recognition error or recognition error rates, were expected to be too large to permit analyses based on the Poisson distribution. It was decided that a parametric analysis of variance would be used to test recognition error rate hypotheses; prior to this analysis the data would be transformed using the arcsin transformation, $y' = 2\arcsin(y^{1/2})$, to remove the relationship between the variance and mean expected because of the Binomial nature of the data.

Non-parametric tests were selected for testing hypotheses regarding tracking scores and subjective fatigue because these data were not expected to meet the assumptions of parametric tests.

Because of the exploratory nature of this research, a level of significance, α, of .10 was selected during the design phase. This value was used in all tests of hypotheses.

H. RESULTS

1. Results for T600 Performance

Appendices H, I, J and K present separate confusion matrices for each of the three operator motor loading - experimental conditions (NTT, CTT and STT) and for all three conditions combined respectively. A matrix element a_{ij} of these matrices indicates the proportion of the time that the T600 "thought" that a subject said word j when the subject actually said word i. Appendix L shows total T600 recognition errors for each subject for each half of each trial under each operator motor loading condition. Mean T600 recognition error rates for each operator motor loading condition, trial half and vocabulary word type, expressed in recognition errors per 100 spoken utterances, are shown in table 1.

Figure 6 is a plot of the recognition error rate observations and figure 7 a plot of the arcsin transformed recognition error rate observations. Figure 7 shows that the parametric analysis of variance homogeneity of variance assumption was adequately met. Since the parametric analysis of variance is quite robust regarding its Normality assumption (Scheffé, 1959), it was felt that this assumption also was adequately met and a parametric analysis of variance was performed on the arcsin transformed data. The results are summarized in table 2. The model for this analysis was:

TABLE 1

MEAN T600 RECOGNITION ERROR RATES*

BY OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION (over all word types and both trial halves)

NTT	10.51%
CTT	14.43%
STT	14.73%

BY TRIAL HALF (over all word types and motor loading conditions)

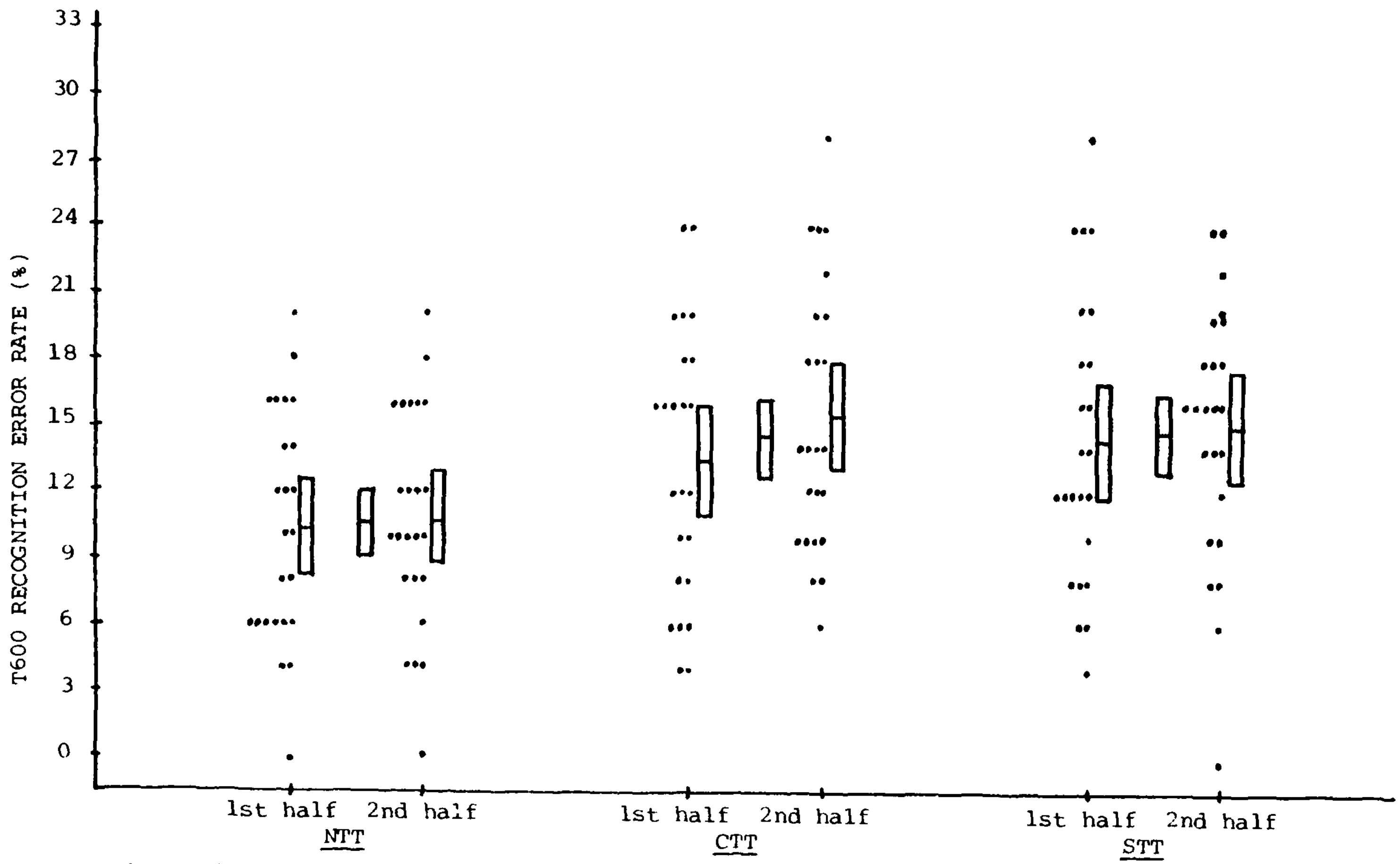
First half	12.71%
Second half	13.73%

BY VOCABULARY WORD TYPE (over all motor loading conditions and both trial halves)

Rhyming	25.67%
Non-rhyming but similar	12.91%
Operational	3.48%

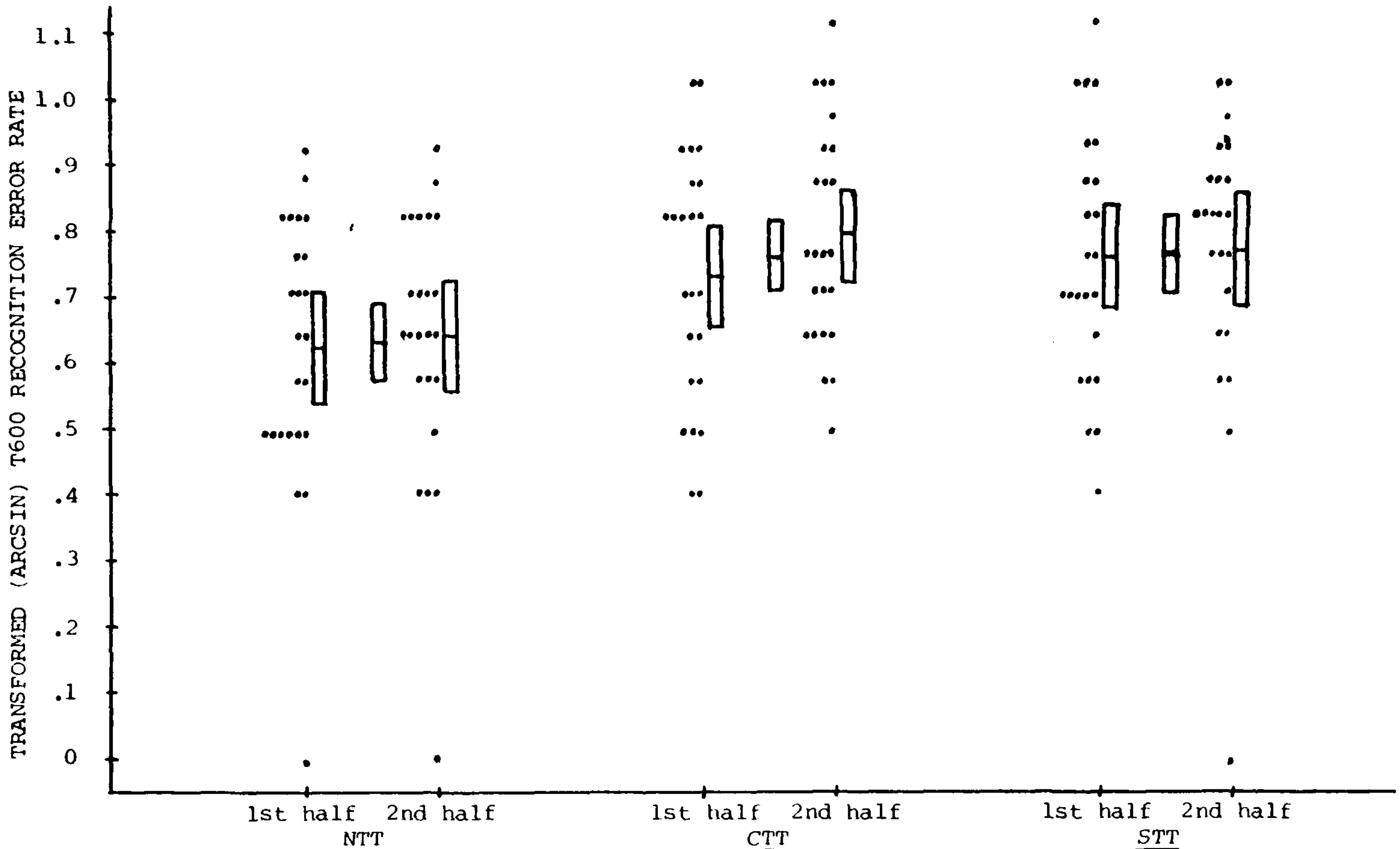
OVERALL 13.22%

* Expressed in recognition errors per 100 spoken utterances. A recognition error was operationally defined in this research to be a failure of the T600 to recognize correctly any vocabulary word which S spoke and includes both incorrect recognition and rejection of vocabulary words; recognition errors do not include those cases where S spoke a word not in the vocabulary (or coughed, sighed, etc.) and the T600 generated a recognition.



Three 95% confidence intervals are shown for each operator motor loading condition, one for the mean of the first half (left-most), one for the mean of the second half (right-most), and one for the overall mean (center). A level of significance, α, of .10 was selected in the experimental design.

FIGURE 6. T600 RECOGNITION ERROR RATE OBSERVATIONS



Three 95% confidence intervals are shown for <u>each</u> operator motor loading condition, one for the mean of the first half (left-most), one for the mean of the second half (right-most), and one for the overall mean (center). A level of significance, α, of .10 was selected in the experimental design.

FIGURE 7. TRANSFORMED (ARCSIN) T600 RECOGNITION ERROR RATE OBSERVATIONS

TABLE 2

ANALYSIS OF VARIANCE FOR T600 RECOGNITION ERROR RATE

Source	df	MS	F
Subjects	23	.129	6.45*
L (Operator motor loading condition)	2	.279	13.95*
H (Trial half)	1	.033	1.65 NS
L x H	2	.0095	
Error	115	.020	

* p <.0005

NS - Not significant, i.e. p >.10

$$Y_{ijk} = u + L_i + H_j + S_k + LH_{ij} + e_{ijk}$$

where Y_{ijk} = arcsin transformed recognition error rate for operator motor loading condition i, trial half j, and subject k; the range of Y_{ijk} is 0 to Π.

u = common experimental contribution to Y_{ijk}

L_i = contribution of operator motor loading condition i, i=1,2,3 (NTT, CTT, STT)

H_j = contribution of trial half j,j=1,2 (first half, second half)

S_k = contribution of subject k, k=1,2,...,24

e_{ijk} = random error

Subject effects were considered to be random; all others were considered to be fixed.

The analysis showed motor loading to be significant ($F=13.95$, $df=2/115$, $p < .0005$). A parametric Range Test (Hicks, 1973) was performed to determine which operator motor loading conditions were statistically different (with respect to T600 recognition error rates) and it was concluded that the only significant differences ($\alpha = .10$) were between condition NTT and both of the other two conditions, CTT and STT.

Trial half was not significant ($F=1.65$, $df=1/115$, $p > .10$). The interaction between operator motor loading and trial half was not significant ($F < 1$).

A non-parametric Friedman two-way analysis of variance (Siegel, 1956) was performed and concluded that recognition

error rate differed by vocabulary word type (rhyming, non-rhyming but similar, and operational) (χ_r^2=46.08, df=2, $p < .0005$). A non-parametric test proposed by Nemenyi (in Kirk, 1968, p. 497) was performed to determine which pairwise comparisons of recognition error rate were significant; it was concluded that all pairwise differences were significant ($p < .01$), i.e., each of the vocabulary word types were different from each other.

Figure 8 shows recognition error rate versus operator motor loading condition for each trial half for each vocabulary word type. Figure 9 is a simplified version of figure 8 showing recognition error rate versus operator motor loading for each trial half.

Subjects were instructed to repeat each vocabulary word heard and to guess with a word in the vocabulary if uncertain of the word. The purpose of this instruction was to ensure that the T600 received the same, or at least nearly the same, utterances for recogntion during each trial half, i.e., each vocabulary word once, and thus provide a common basis for comparison of T600 recognition errors. Despite the instruction instances arose where subjects either did not speak any word or spoke a word not in the vocabulary; these are tabulated in Appendix M. T600 recognition errors, as operationally defined in this research, could not occur in these instances and the following adjustment was made to establish a reasonably common basis for comparison. If x T600 recogni-

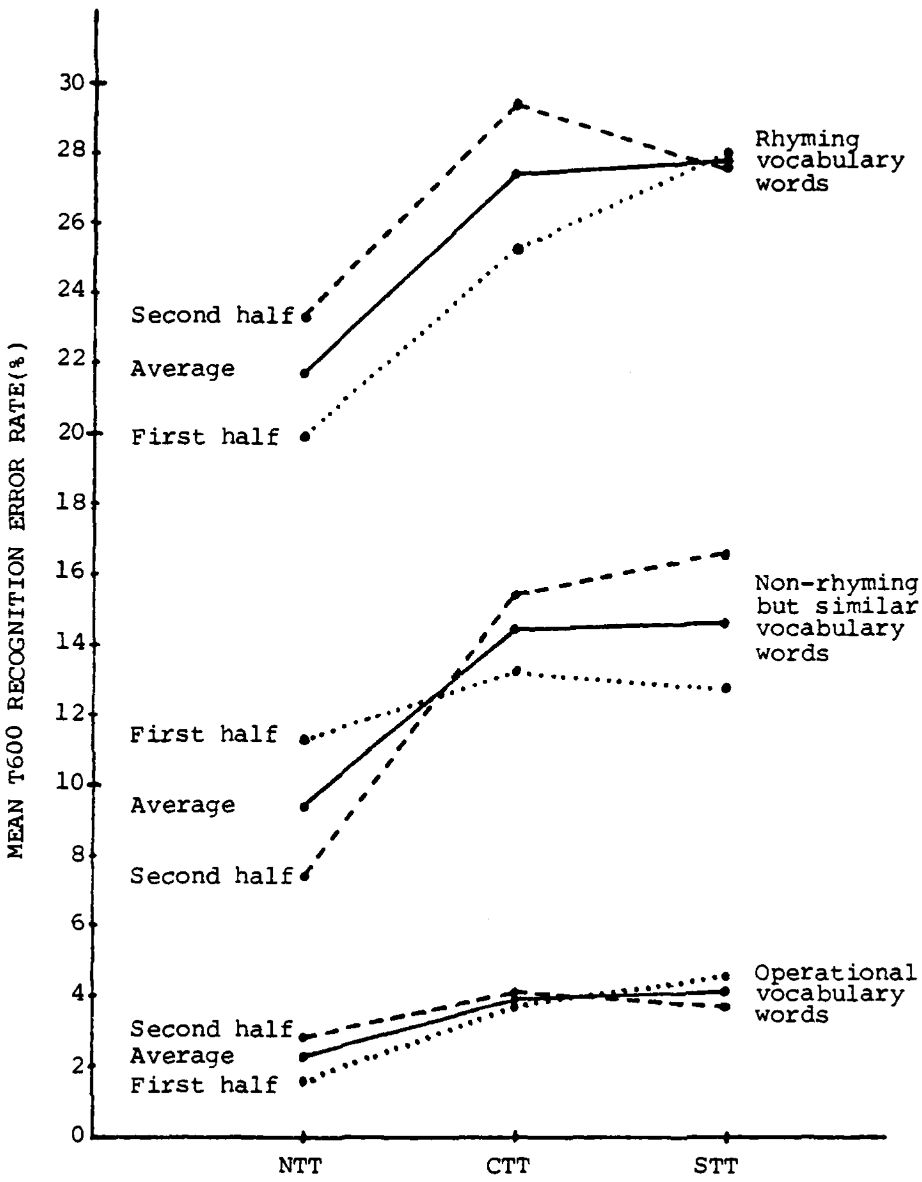


FIGURE 8. MEAN T600 RECOGNITION ERROR RATES
(in recognition errors per 100 spoken utterances)

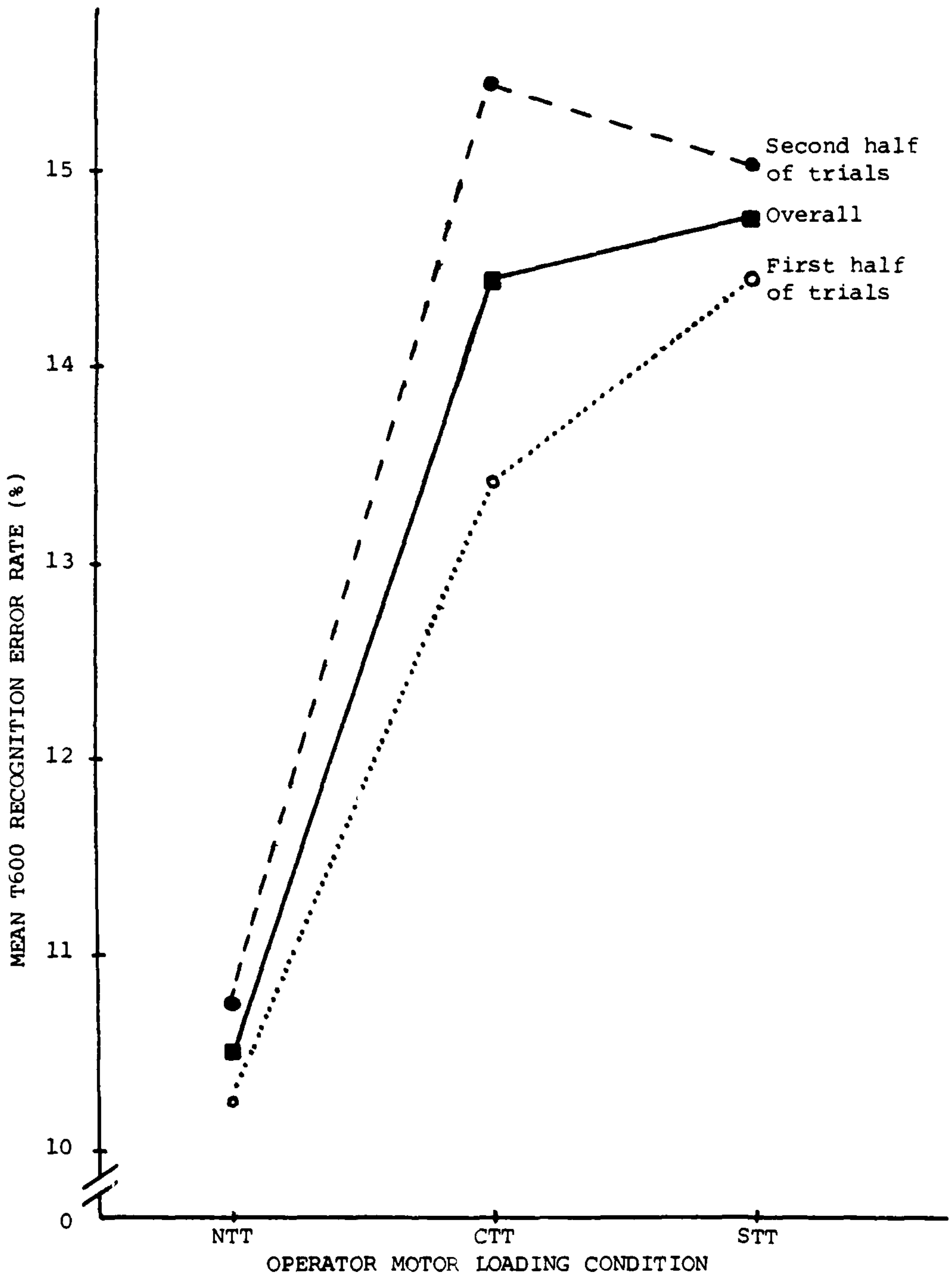


FIGURE 9. MEAN T600 RECOGNITION ERROR RATES
(in recognition errors per 100 spoken utterances)

tion errors occurred in a particular trial half for a subject and that subject made y errors of the above type in the trial half, then the error rate observation on which the analysis was based was $x/(50-y)$, not $x/50$.

2. <u>Results for Subject Performance</u>

Appendix M shows total subject verbal errors for each subject for each half of each trial under each operator motor loading condition. Mean subject verbal error rates for each motor loading condition, trial half and vocabulary word type, expressed in subject verbal errors per 100 words presented to the subject for repetition (i.e., each word of the 50 word vocabulary twice), are shown in table 3.

A test based on the Poisson distribution (Cox and Lewis, 1966, p. 231-234) was performed on the subject verbal error rate data and showed the operator motor loading condition effect to be significant ($p < .05$, $\alpha = .10$).

The hypothesis regarding subject verbal error rate versus trial half was not tested as the mean error rate was the same for each trial half (see table 3).

Subject tracker time on target scores are shown in Appendix N. A non-parametric Wilcoxon matched-pairs signed-ranks test (Siegel, 1956) was performed to determine if tracker performance (as indicated by time on target) was statistically different when tracking the two different paths. The test concluded that time on target scores were statistically greater when tracking the circular path than when tracking the

TABLE 3

MEAN SUBJECT VERBAL ERROR RATES*

BY OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION

NTT	.29%
CTT	.17%
STT	.54%

BY TRIAL HALF

First half	.33%
Second half	.33%

BY VOCABULARY WORD TYPE

Rhyming	.13%
Non-rhyming but similar	.60%
Operational	.31%

OVERALL .33%

* Expressed in subject verbal errors per 100 vocabulary words presented to S via the headset. A subject verbal error was defined in this research to be a failure of the subject to repeat correctly the presented vocabulary word. This failure could be either a failure to respond (omission) or responding with a non-vocabulary word or the wrong vocabulary word (commission).

square-like path ($p < .00006$).

The results of the subjective fatigue enquiry are shown in Appendix O. Numerical scores shown were obtained by multiplying the number of items scored "better than" by two and adding the number of items scored "same as", as recommended by Pearson and Byars (1956). A non-parametric Friedman two-way analysis of variance was performed on this data and it was concluded that subjective fatigue was the same for the three operator motor loading conditions ($\chi_r^2 = 1.90$, df=2, $p > .3$, $\alpha = .10$).

3. Other Results

The following were investigated graphically:

a. T600 recognition error rate versus subject verbal error rate; and,

b. Tracker scores versus subject verbal error rates. No relationships were apparent. Spearman rank correlation coefficients between subject tracker scores and T600 recognition error rates were calculated for each tracker condition. The coefficient for condition CTT was not significant (r_s(CTT) = -.304, r_s(critical) = ±.343, two-tailed test, α=.10). However, the coefficient for condition STT was significant (r_s(STT) = -.401, r_s(critical) =±.343, two-tailed test, α=.10); i.e., there was a significant tendency for subjects to do either well or poorly on both the square tracking and voice input tasks but not poorly on one and well on the other.

III. DISCUSSION

Operator motor loading was found to affect significantly the performance of the voice recognition system in that mean T600 recognition error rates in the two conditions involving concurrent tracking were 39% greater than the mean error rate of the no tracking condition. Although mean error rates appeared greater in the second half of trials than in the first half (see table 1 and figure 9), the difference was not significant ($p > .10$).

The hypotheses regarding T600 recognition error rates were retested using operational words only and tests based on the Poisson distribution. The trial half effect was found to be not significant ($p > .5$, two-tailed test, $\alpha = .10$), as it was when using the whole vocabulary. The operator motor loading condition effect was significant ($p < .10$, $\alpha = .10$), as it was when using the whole vocabulary. This last result supports the following generalization: recognition error rate will be greater with concurrent motor loading (like conditions CTT or STT) than without (condition NTT) even if the vocabulary is comprised entirely of operational-like utterances, i.e., a real world vocabulary versus the artificial vocabulary of the experiments (assuming the operator trained the system without concurrent motor tasking, i.e., in the usual manner).

Operator motor loading condition had a significant effect on subject verbal error rate, as expected. Subject verbal error rate did not differ by trial half.

The subjective fatigue checklist failed to disclose significant differences between any of the three operator motor loading - experimental conditions. This was probably partly because the effects of order of presentation of the conditions dominated any possible condition effects during subjects scoring of the checklists. (Several subjects advised the experimenter after a tracking condition that the condition was more fatiguing than condition NTT but they had to score the tracking condition higher because it was the last, or next to last, condition and the subject felt good because the end was at hand.)

<u>It is emphasized</u> that the <u>recognition error rates</u> obtained with the T600 in this experiment <u>are at least ten times what has commonly been found</u>. <u>These higher recognition error rates were deliberately sought</u> by the experimenter to facilitate detection of factors influencing system performance and are primarily due to the special vocabulary employed. The results using the special vocabulary also indicated the recognition performance degradations that a real world operator may encounter when using different phrases that are similar to one another in sound, such as "above glide slope" and "below glide slope" or "VHF" and "UHF".

The author is continuing to investigate the use of the special vocabulary and the effects of task-induced stress on performance of a voice recognition system.

APPENDIX A

VOCABULARY LISTING (BY WORD TYPE)

RHYMING

gale	tale	gold	cold
game	came	bark	park
tip	dip	big	pig
beat	peat	ten	den

NON-RHYMING BUT SIMILAR

sap	sat	peas	peace
race	raze	save	safe
lake	late	kit	kid
mad	mat		

OPERATIONAL

list	course	attack	refuel
time	plot	bingo	cancel
speed	air	report	proceed
dive	fire	distance	label
drop	launch	copy	station

A vocabulary listing in the order in which the words were trained is attached to the written instructions initially given to subjects and shown in Appendix C.

APPENDIX B

SUBJECT DATA SHEET

Subject number: _____ Name: ___________________________ Age: _____

Time/date: ___________ Service: ________________________________

Rank: ______________ MOS (in words): ____________________________

Do you object to being taperecorded during the experiment? If you do, stop filling out this form and advise the experimenter now; otherwise, continue.

How many hours experience have you had on voice recognition equipment in the last six months?

_________ hours (approximately)

How many hours experience have you had on pursuit tracking devices in the past year?

__________ hours (approximately)

Do you have a speech or hearing impediment? Yes No (circle one)

Do you want a post participation briefing on your performance and on the hypotheses being tested by the experimenter? Note that if you request such a briefing, you must agree not to discuss this with anyone other than the experimenter so that no subject will learn what results are expected prior to his participation in the experiment; such prior knowledge could invalidate the results of the experiment.

Yes No (circle one)

After you have completed participation in the experiment you will be asked to write below any comments which you think may be useful to the experimenter. If you have any questions now, please ask the experimenter. Otherwise, give him this form now and start reading the pages titled "INTRODUCTORY REMARKS/ RECOGNIZER VOCABULARY TRAINING".

POST EXPERIMENT COMMENTS

(continue on reverse side if this space is insufficient)

THANK YOU FOR YOUR PARTICIPATION

APPENDIX C

WRITTEN INSTRUCTIONS

INTRODUCTORY REMARKS / RECOGNIZER VOCABULARY TRAINING

INTRODUCTORY REMARKS

This experiment involves analysis of a combined human operator / voice recognition equipment system under various conditions of operator motor loading. The actual experiment will be carried out in a sound-proof booth and subject - experimenter communication during the actual experiment will be via the booth intercom system; however, you may remove the headset assembly during break periods and leave the booth.

CAUTION: The mounting of the voice recognizer microphone on the headset assembly is very delicate, easily damaged, and difficult to repair. Please be careful while handling this assembly.

Please carry out the experiment exactly as directed and do not discuss your performance with anyone other than the experimenter as inappropriate subject prior knowledge could invalidate the results.

VOICE RECOGNIZER VOCABULARY TRAINING

The 50 word vocabulary being used with the voice recognizer in this experiment is attached to these instructions. You will be required to repeat each word of this vocabulary ten times to train the recognizer to recognize your particular vocalizations of each word. To facilitate recognition by the voice recognizer, you should include in the ten repetitions

as many as possible of the different ways you might say the word in normal speech; for example, use different intonations and emphasis, and small variations in volume.

In order to keep track of the number of times you say each word, and to reduce breath noise, it is best to speak the 10 repetitions in several groups. For example, if the word is zero, it is better to group them as:

	000-000-0000
or	000-000-000-0
rather than as	0000000000
or	0-0-0-0-0-0-0-0-0-0

Please observe the following guidelines while inputting voice data to the recognizer both during training and later during the actual experiment.

a. Speak each word crisply and quickly but do not over-pronounce; for example, words ending in "t" - delete final "t" if more natural.

b. Be sure to leave a distinct pause (specifically, at least one-tenth of a second of silence) between each word so that the recognizer can distinguish the end of one word from the beginning of the next. Similarly, do not leave a period of silence within a word or the recognizer will mistake it for two separate words.

c. Avoid breathing into the microphone at the end of words as this will generate false inputs to the recognizer.

d. Microphone location is very important and should be kept constant throughout the experiment; i.e., adjust it if it gets out of place. The experimenter will initially demonstrate correct microphone placement.

From this point on instructions will be given to you verbally by the experimenter. Please advise him if you have any questions now.

VOCABULARY LISTING (IN TRAINING ORDER)

0. attack
1. list
2. gale
3. tale
4. bingo
5. sap
6. sat
7. time
8. gold
9. cold
10. cancel
11. peas
12. peace
13. speed
14. game
15. came
16. distance
17. race
18. raze
19. copy
20. bark
21. park
22. launch
23. save
24. safe
25. refuel
26. tip
27. dip
28. drop
29. lake
30. late
31. course
32. big
33. pig
34. report
35. kit
36. kid
37. plot
38. beat
39. peat
40. proceed
41. mad
42. mat
43. fire
44. ten
45. den
46. label
47. air
48. station
49. dive

APPENDIX D

EXPERIMENTER AIDE-MEMOIRE

I. PRELIMINARY CHECKS

A. EQUIPMENT POWER

Turn on master power switch and ensure that the following devices are turned on and ready for use.

-voice processor
-voice recognition system tape recorder
-CRT
-Miniterm
-Maico audiometer
-reel-to-reel tape recorder
-cassette tape recorder
-tracker and timing clocks (2)
-booth lighting

B. MINITERM

Check that the Miniterm is in the "local" mode and that the paper remaining is adequate for the next subject; then write this subject's name on top of the paper.

C. T600

Read in E's experimental vocabulary tape then check T600 and Miniterm operation with several vocabulary words. First ensure that the microphone level control is set to "five".

D. TRACKER AND TIMING CLOCKS

Ensure that the circular track is in place and that the following controls are set as indicated.

Tracker - Speed to 40 rpm
- Motor to "reverse" (clockwise rotation)
- Timer switch ON
- Power switch ON
- Lamp switch ON
- Sensitivity control to "one o'clock" position

Control clock - Buzzer switch ON
- Outlet plug switch OPEN

E. MAICO AUDIOMETER

Ensure that the following controls are set as indicated.

-Mixer control to BOTH-BOTH
-monitor gain (L to 0 and pulled out, R to 6 and pushed in)

-talk-back gain to 5
-talk-over gain to 3
-output control to AIR (both L and R channels)
-test stimulus control to TAPE (both L and R channels)
-R volume control to 60, R meter ON, and R meter gain to 6
-L volume control to 0, L meter OFF
-test presentation control to ON (both L and R channels)

F. REEL-TO-REEL TAPE RECORDER

Ensure that the following controls are set as indicated.
-channel to 1-4
-monitor to TAPE
-SOS off
-equalization to 7 1/2
-tape speed to 7 1/2
-tape type to NORMAL (WIDE RANGE)

Put on the tape used to signal S vocabulary words to repeat and check that the signal reaches both channels of the subject headset. Then reset the tape to the beginning of the practice section.

G. CASSETTE TAPE RECORDER

Ensure that the recorder is in the mono mode. Place a cassette into the recorder and record the subject number onto the beginning of the cassette using the booth microphone. Remember to turn on the cassette microphone mixer first and turn it off after. Check that the subject number was recorded properly.

II. COMPLETION OF SUBJECT DATA SHEET AND INTRODUCTORY INSTRUCTIONS

Write the subject number on the "Subject Data Sheet". Have the subject complete this sheet then answer any questions he may have.

Have the subject read the introductory instructions ("Introductory Remarks / Recognizer Vocabulary Training"). While he is doing this check his data sheet. Answer any questions he may have.

III. DEMONSTRATION OF T600 OPERATION AND LIMITATIONS

Remove the T600 microphone (and the headset on which it is mounted) from the booth and reconnect the microphone outside the booth. Demonstrate to S the importance of the guidelines that he just read, especially what happens if a pause is not left between words and what happens if a pause is left within a word. Let S "play with" the T600 in the recognition mode for several minutes. Be sure to tell him that the T600 will recognize him much better after it has been trained with his versions of the vocabulary words. (E's versions are used during this demonstration.) Reconnect the T600 microphone and headset inside the booth after this demonstration. Note: be sure to demonstrate correct microphone placement to S before letting him "play with" the T600.

IV. T600 VOCABULARY TRAINING

Show S to the booth, seat him and explain the purpose of the two microphones as follows.

> "The microphone mounted on the headset is connected only to the T600. This other microphone is connected to a tape recorder so that I can record what you say during the experiment for analysis later; this microphone is live at all times and also permits me to hear what you say to me."

Explain to S the procedure which will be used in vocabulary training as follows.

> "Next we will train the T600 with the 50 word vocabulary which you have attached to the 'Introductory Remarks / Recognizer Vocabulary Training' sheets. Refer to this listing as we train the T600. The 50 words will be trained one at a time. I will prompt you with something like 'Enter the first word now, please'. Then you will enter your ten versions of the first word, keeping in mind the instructions which you just finished reading. As we get going I'll shorten the prompting to something like 'Next word please' to save time.
>
> "If you have trouble keeping track of the number of repetitions just keep repeating the word and I'll say 'stop' after the tenth repetition. Proper grouping as detailed in the instructions will help you keep count.

"Notice that some of the vocabulary words are similar. They have been paired and the differences underlined in the vocabulary listing for emphasis. Be sure to pronounce each of these words distinctly and correctly so that the T600 will be able to distinguish them. To obtain adequate recognition performance from the T600 it may be necessary for you to pronounce some words a little more distinctly than you normally do, both in training and later for recognition. However, the key word here is 'little'; speak as naturally as possible.

"I'll be turning the microphone switch on and off for each different word, so if you want to clear your throat or say something to me do so a couple of seconds after completing the tenth version of a word; otherwise, keep silent between the training of different vocabulary words.

"If any word needs retraining I'll advise you why and we will retrain the word immediately, rather than waiting until the end of the vocabulary.

"Here's a special pen which will write on the plastic covering your copy of the vocabulary. Use it to check off words as we finish training them. Please return it to me after the vocabulary has been trained and tested.

"We can take a break after word number 24 if you wish; I'll check with you at that time. Training the entire vocabulary will take about 20 minutes. Do you have any questions?"

Remind S of the delicate mounting of the T600 microphone on the headset. Have him put on the headset and ensure that he positions the microphone correctly. Advise him that you will contact him over the headset then leave the booth and close the door.

Put on your headset and contact S using the talk-over switch and microphone of the Maico audiometer. Adjust the talk-over gain as necessary so that S can clearly hear what you say.

Train each word of the vocabulary as follows.
- enter "CNTRL-U", the word number, and a carriage return on the T600 control
- confirm that the correct word is called for
- turn on the T600 microphone switch
- press the talk-over switch and prompt S to train the word ("next word, please")

- after he has entered his tenth version of the word turn off the T600 microphone switch (and tell him to stop if he is still repeating the word)
- if the word has to be retrained, tell S why and retrain it; else,
- check off the word on your copy of the vocabulary and train next word.

Ask S if he wishes to take a rest break after word number 24 has been trained. Take a break if he does; otherwise, finish training the vocabulary and then take a rest break.

V. RECOGNITION CHECK / RETRAINING (AS NECESSARY) AND WORD REPETITION PRACTICE

Explain to S that next the vocabulary will be checked for recognition and that words will be retrained as necessary and that after that he will be given a practice session involving repeating a sequence of vocabulary words, one word at a time, that will be presented to him via his headset.

"Next we'll check that the T600 now recognizes your versions of the 50 vocabulary words. We'll check the words one at a time. Any word which is not correctly recognized at least twice in three tries will be retrained. I'll be prompting you as follows. If I say 'next', say the next word three times. If the T600 correctly recognized at least two of the three repetitions, I'll say 'next' and we'll go on to the next word. If it did not, I'll ask you to retrain the word before we continue. Then we'll recheck recognition and continue or retrain again as appropriate. If either word of a rhyme or nonrhyming but similar word pair requires retraining, we'll recheck recognition of both words of the pair and retrain and recheck as necessary before continuing.

"When we've finished checking and retraining the vocabulary, I'll play a 2 1/2 minute recording of a random ordering of the vocabulary words to you. Words are three seconds apart and you are to repeat each word, one at a time, for recognition by the T600. Try to repeat each word. If you are uncertain of a word, guess with a word in the vocabulary. Before you start hearing words to repeat, you will hear the warning 'this part will begin in five seconds' and then five seconds later you will hear the first word that you are to repeat. At the end you will hear 'end of this part'. At that time we will take a rest break. Do you have any questions?"

Show S to the booth and have him put on the headset. Check that he has the T600 microphone positioned correctly then leave the booth and close the door. Put the T600 in recognition mode ("CNTRL-W", "N", then carriage return), put on your headset, and confirm that S is ready.

Turn on the T600 microphone switch and ask S to say the first word. Then check recognition of the vocabulary words, retraining where necessary.

When all vocabulary words have been checked for recognition and retrained as necessary, ensure that S is ready to start repeating the words recorded on the practice tape. If he is,
-put the T600 in recognition mode ("CNTRL-W","N", and carriage return)
-turn on the cassette tape recorder microphone mixer (two LH-most controls to 12 o'clock)
-start recording on the cassette tape recorder
-start the practice tape on the reel-to-reel tape recorder
-when you hear the 5 second warning start, turn on the T600 microphone switch.

When the end of the practice tape is reached:
-advise S to remove the headset, leave the booth, and take a break
-stop the cassette tape recorder and ensure that it recorded properly
-turn off the cassette tape recorder microphone mixer (two LH-most controls fully counter-clockwise)
-T600 microphone switch to OFF
-rewind the practice tape back to the beginning of the practice session.
-ask S if the volume was adequate and adjust it as necessary
-answer qny questions that S may have.

VI. EXPLANATION OF EXPERIMENTAL CONDITIONS

Explain the experimental conditions to S as follows.

"During the actual experiment, you will be exposed to three different conditions of motor loading, which I'll explain later. Each condition will last five minutes and there will be a short break after each condition.

"During all three conditions you will be required to repeat vocabulary words presented to you exactly as during the practice you just finished. The sequences of words will be different but the pacing is the same, i.e., a word every three seconds, and the same warnings are used at the beginning and end. Remember, you are repeating these words for recognition by the T600.

"During two of the conditions you will be simultaneously tasked on the pursuit tracker. A different tracker task will be used during each of these two conditions and these will be explained in a couple of minutes. During the third condition all you are to do is repeat the words you hear for recognition by the T600.

"In all three conditions repeating the words for recognition by the T600 is the more important task and you are to repeat each word, guessing with a word from the vocabulary if you are uncertain, just as you did during the practice you just completed."

VII. TRACKER BRIEFING AND PRACTICE

Tell S the names of the two tracker tasks and the three experimental conditions as follows.

"The two tracker tasks which you will be performing are called Circular Tracking Task (CTT) and Square Tracking Task (STT); the names of the corresponding experimental conditions are the same. The third experimental condition, during which you only have to repeat the words you hear, is called No Tracking Task (NTT).

Explain the tracking tasks to S as follows.

"During the tracking tasks you will be required to try to keep the head of the tracker wand (show S the wand and the wand head) positioned over the light which will move around either a circular or square path, depending on the task (show S the circular path and the light). In both cases the angular velocity is a constant 40 rpm. In the Circular Tracking Task, because the path is a circle, the light will travel at a constant speed. However, in the Square Tracking Task, because the path is a square, the light will not travel at constant speed; it will travel faster nearer the corners than on the centers of the sides.

"In both cases a stop clock will automatically record the total time during which you keep the wand head positioned over the light. This is called time on target (TOT) and will be your tracker score. You are to attempt to maximize this.

"Both tracking tasks are to be performed while standing; you are to sit for the No Tracker Task condition. You may hold the wand anyway you wish.

"It's easy to cheat at these tracking tasks. For example, you can change the angular velocity (show S how) or simply hold the wand head up to the overhead light to "fool" the stop clock. Please follow the instructions that I give you and don't cheat."

"I do not require you to achieve any particular proficiency level on either of the Tracker tasks. It is sufficient that you understand the tasks and perform them to the best of your current abilities. However, I do require that you do this for the full five minutes of each condition; i.e., don't get frustrated, say with the Square Tracking Task, and completely stop tracking and only repeat the words that you hear. You must keep trying to maximize your TOT scores.

Advise S that he now has a couple of minutes to practice on the tracker using the circular path. Zero out the TOT clock. Set the control clock to 2 1/2 minutes and start it to start the tracker for the practice. After the practice tell S his TOT score.

VIII. COMBINED TRACKER / WORD REPETITION PRACTICE

When S has finished his practice on the tracker explain to him that he will next be given a 2 1/2 minute combined Tracker / Word Repetition practice, as follows.

"You will next be given a combined Tracker / Word Repetition practice. I will play the same 2 1/2 minute recording of a random ordering of the vocabulary words which you heard in the first practice. You are to repeat these words, one at a time as before, for recognition by the T600. As before, the tape begins with the warning 'this part will begin in five seconds' and five seconds later you will hear the first word that you are to repeat; at the end of the tape you will hear 'end of this part'.

"While you are repeating the words you hear, you are to simultaneously perform the Circular Tracking Task as well as you can, i.e., try to maximize your TOT score. Remember though that repeating the words for recognition by the T600 is the more important task and that you are to try to repeat each word that you hear, guessing with a word from the vocabulary if you are uncertain, just as before.

"If you want me to adjust the volume of the headset signal, i.e., the words for repetition, be sure to let me know right after this practice; the volume must be kept constant during the three conditions of the actual experiment.

"We will take a rest break after this practice. Do you have any questions?"

Show S to the booth and have him put on the headset. Check that he has the T600 microphone positioned correctly then leave the booth and close the door.

Ensure that the TOT clock is zeroed. Put on your headset and confirm that S is ready. If he is,

-put the T600 in recognition mode ("CNTRL-W", "N", and carriage return)
-set the control clock to 2 1/2 minutes
-turn on the cassette tape recorder microphone mixer (two LH-most controls to 12 o'clock)
-start recording on the cassette tape recorder
-start the practice tape on the reel-to-reel tape recorder
-turn on the T600 microphone switch
-when you hear the first word for repetition start the tracker by turning the control clock ON

Monitor S's word repetition and TOT score to ensure that S is adhering to instructions. Ensure that the T600 is functioning properly.

When the end of the practice tape is reached:

-turn the control clock OFF
-advise S to remove the headset, leave the booth and take a break
-stop the cassette tape recorder and ensure that it recorded properly
-turn off the cassette tape recorder microphone mixer (two LH-most controls fully counter-clockwise)
-T600 microphone switch to OFF
-position the reel-to-reel tape at the beginning of the first experimental condition section
-ask S if the volume was adequate and adjust it as necessary
-tell S his TOT score and explain to him that he will not receive any more feedback on his performance until the end of the experiment
-zero out the TOT clock
-answer any questions that S may have
-advance the Miniterm paper several lines

While S is taking his break fill in the top line of his T600/Subject Performance Summary Sheet (sample attached to this aide-memoire) and the top line of his three Subjective Fatigue Checklists. Turn them over so that S can not determine in advance the order of condition presentation.

IX. ACTUAL EXPERIMENT

For each experimental condition, install the appropriate tracker "path". Advise S what condition is next (and only what condition is next, i.e., not the whole sequence of conditions). Advise him that the condition will last for five minutes and remind him that repeating the words for recognition by the T600 is the more important task, to try to respond to each word, and to guess with a word from the vocabulary if he is uncertain.

Show S to the booth and have him put on the headset. Check that he has the T600 microphone positioned correctly then leave the booth and close the door.

Ensure that the TOT clock is zeroed. Put on your headset and confirm that S is ready. If he is,

- -put the T600 in recognition mode ("CNTRL-W", "N", and carriage return)
- -set the control clock to 5 minutes
- -turn on the cassette tape recorder microphone mixer (two LH-most controls to 12 o'clock)
- -start recording on the cassette tape recorder
- -start the tape on the reel-to-reel tape recorder
- -turn on the T600 microphone switch
- -when you hear the first word for repetition start the tracker by turning the control clock ON (as applicable)

Monitor S's word repetition and TOT score to ensure that S is adhering to instructions. Ensure that the T600 is functioning properly. Write the name of the experimental condition (i.e., NTT, CTT, or STT) on the Miniterm output.

When the end of the tape recording for the experimental condition is reached:

- -turn the control clock OFF
- -turn off the T600 microphone switch
- -advise S to wait in the booth and that he may remove the headset
- -stop the cassette and reel-to-reel tape recorders
- -go to the booth with a copy of the Subjective Fatigue Checklist Instructions and S's Checklist for this condition and tell S "Please fill out this checklist in accordance with these instructions."
- -copy the TOT onto S's T600/Subject Performance Summary Sheet while S fills out the checklist then zero out the TOT clock and turn over the Performance Summary sheet so that S can not determine his TOT score
- -ensure that the cassette tape recorder recorded properly

- turn off the cassette tape recorder microphone mixer (two LH-most controls fully counter-clockwise)
- position the reel-to-reel tape at the beginning of the next experimental condition section
- advance the Miniterm paper several lines.

When S has filled out the Subjective Fatigue Checklist, take it from him and advise him that he may take a short break before he starts the next condition. Do not tell him what the next condition will be at this time.

If the condition completed was the last condition, give S back his Subject Data Sheet so that he can record any comments he may have. When he returns this, tell him his TOT scores and brief him on the hypotheses being tested in the experiment (depending on his wishes as indicated on his Subject Data Sheet), answer any questions he may have and thank him for participating.

T600 / SUBJECT PERFORMANCE SUMMARY

Subject number ________ Time/date ________________ Order conditions presented ________________

OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION

	NTT		CTT		STT	
	1st half	2nd half	1st half	2nd half	1st half	2nd half
T600 PERFORMANCE						
RE's in response to:						
Rhyming words						
Non-rhyming but similar words						
Operational words						
Total						
SUBJECT PERFORMANCE						
A. S VERBAL ERRORS (in response to)						
Rhyming words						
Non-rhyming but similar words						
Operational words						
Total						
B. ON TRACKER Time on target						
C. SUBJECTIVE FATIGUE SCORE						

APPENDIX E

ORDER OF PRESENTATION OF CONDITIONS

SUBJECT NUMBER	ORDER OF PRESENTATION OF CONDITIONS		
1	CTT	NTT	STT
2	STT	NTT	CTT
3	NTT	CTT	STT
4	CTT	STT	NTT
5	STT	CTT	NTT
6	NTT	STT	CTT
7	CTT	NTT	STT
8	NTT	STT	CTT
9	NTT	CTT	STT
10	STT	CTT	NTT
11	CTT	STT	NTT
12	STT	NTT	CTT
13	NTT	STT	CTT
14	STT	CTT	NTT
15	NTT	CTT	STT
16	CTT	STT	NTT
17	STT	NTT	CTT
18	CTT	NTT	STT
19	NTT	STT	CTT
20	CTT	NTT	STT
21	STT	NTT	CTT
22	STT	CTT	NTT
23	CTT	STT	NTT
24	NTT	CTT	STT

APPENDIX F

RANDOM ORDERINGS OF THE VOCABULARY

PRACTICE	FIRST CONDITION		SECOND CONDITION	
raze	ten	list	gale	ten
pig	dip	tale	fire	tale
mat	label	park	big	den
list	den	distance	race	cold
course	game	kid	lake	list
copy	air	report	time	time
station	gold	late	course	sap
dive	speed	save	game	launch
peat	attack	gale	ten	gale
plot	beat	drop	mat	drop
kit	race	bingo	list	station
launch	proceed	raze	tip	distance
attack	tip	came	cold	copy
park	cancel	sap	late	peas
save	sat	pig	mad	pig
ten	fire	race	proceed	late
air	launch	cancel	label	peace
came	tale	big	dip	dip
sat	late	station	safe	tip
gold	course	air	attack	report
report	peat	peas	speed	gold
game	gale	ten	dive	beat
safe	station	game	beat	sat
dip	mat	lake	bark	bingo
label	big	mat	refuel	kid
den	pig	attack	park	cancel
cold	sap	dip	kid	game
time	came	safe	tale	raze
fire	raze	plot	raze	label
race	save	den	kit	bark
tip	copy	peat	sat	race
beat	list	peace	report	park
cancel	bingo	course	station	speed
lake	drop	bark	sap	kit
mad	refuel	label	save	peat
kid	peas	dive	distance	save
peas	safe	fire	cancel	attack
proceed	lake	sat	launch	came
tale	mad	tip	air	lake
big	cold	kit	peace	big

peace
gale
bark
late
drop
speed
distance
refuel
sap
bingo

dive
time
peace
plot
kit
report
park
distance
bark
kid

speed
refuel
beat
proceed
cold
gold
time
mad
copy
launch

den
peat
bingo
came
peas
plot
copy
pig
drop
gold

mad
dive
course
fire
mat
refuel
plot
air
proceed
safe

THIRD CONDITION

pig
park
attack
peat
peace
sat
beat
list
late
speed

came
beat
speed
pig
cancel
sap
distance
copy
station
course

dip
came
launch
bingo
mad
big
save
air
plot
refuel

mad
air
plot
dive
peace
sat
kid
drop
refuel
fire

ten
time
gold
peas
report
cold
den
cancel
course
copy

dip
label
raze
list
park
late
game
save
lake
proceed

mat
fire
dive
safe
kit
tip
race
bark
proceed
kid

den
bark
bingo
mat
big
safe
kit
tip
peat
attack

distance
station
label
raze
drop
gale
sap
game
tale
lake

tale
race
cold
launch
peas
time
gale
report
gold
ten

APPENDIX G

SUBJECTIVE FATIGUE CHECKLIST

Subject number ________ Experimental condition ____________

FEELING TONE CHECK LIST

No.	Better than	Same as	Worse than	Statement
1.	( )	( )	( )	slightly tired
2.	( )	( )	( )	like I'm bursting with energy
3.	( )	( )	( )	extremely tired
4.	( )	( )	( )	quite fresh
5.	( )	( )	( )	slightly pooped
6.	( )	( )	( )	extremely peppy
7.	( )	( )	( )	somewhat fresh
8.	( )	( )	( )	petered out
9.	( )	( )	( )	very refreshed
10.	( )	( )	( )	ready to drop
11.	( )	( )	( )	fairly well pooped
12.	( )	( )	( )	very lively
13.	( )	( )	( )	very tired

Have you checked each statement?

INSTRUCTIONS FOR COMPLETING FEELING TONE CHECKLIST

People feel different at various times for various reasons. Some arise after a night's rest feeling "quite rested" while others may feel "a little tired". A hard day's work or a vigorous workout at the gym may make you feel "fairly well pooped"; yet, a shower, a cup of coffee, or merely a few minutes relaxing in a comfortable chair may make you feel "very refreshed".

I would like to find out how you feel right now. On the accompanying sheet, you will see 13 statements which describe different degrees of freshness or peppiness and tiredness. For each statement you will have to determine in your own mind whether you feel at this instant (1) "Better than", (2) the "Same as", or (3) "Worse than" the feeling described by that statement. Having done this you will then place an "X" in the appropriate box.

Consider the following example:

No.	Better than	Same as	Worse than	Statement
0.	( )	( )	( )	somewhat tired

If right now you felt "somewhat tired" you would place an "X" in the box marked "Same as". If, however, you felt fresh or full of pep you would check the box marked "Better than" because you would be feeling better than "somewhat tired". On the other hand, if you felt exhausted you would place an "X" in the box marked "Worse than".

Take each statement in order; do not skip around from one to another. Read each statement carefully so that you understand what it means. It may help you to understand some statements if you mentally insert the words "I feel" or "I am" before the statement.

This is not a test. You have all the time you need.

APPENDIX H

CONFUSION MATRIX FOR OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION NTT

The matrix element a_{ij} indicates the proportion of the time that the T600 "thought" that a subject said word j when the subject actually said word i. The last column, annotated "beep", indicates the proportion of the time that the T600 rejected vocabulary word i and "beeped".

Several rows do not sum to exactly 1.00; this is because of inaccuracy in the elements of the row caused by rounding to two decimal places.

	GALF	TALE	GAME	CAME	TIP	DIP	BEAT	PEAT	GOLD	COLD	BARK	PARK	BIG	PIG	TEN	DEN	SAP	SAT	RACE	RAZE	LAKE	LATE	MAD	MAT	PEAS	PEACE
GALF	.92	.06																								
TALE	.02	.98																								
GAME	.02		.75	.17									.02			.02										
CAME			.10	.75											.06	.02										
TIP					.67	.25									.02											
DIP					.04	.85									.02	.02										
BEAT							.69	.21																		.02
PEAT							.23	.73																		
GOLD									.81	.17																
COLD									.08	.85																
BARK											.71	.25														
PARK											.29	.71														
BIG													.81	.15		.02										
PIG				.02									.27	.71												
TEN					.02										.79	.19										
DEN						.06								.02	.15	.75										
SAP																	.90	.10								
SAT																	.09	.91								
RACE																			.92	.08						
RAZE																			.06	.94						
LAKE																					.90	.08				
LATE								.04													.04	.90				
MAD																							.96	.04		
MAT																							.02	.94		
PEAS							.02	.02																	.67	.09
PLACE																										1.00
SAVE																										
SAFE																										
KIT					.06																					
KID														.02		.02										
LIST																			.02							
TIME																										
SPEED								.02																		
DIVE																										
DROP																										
COURSE																										
PLOT																										
AIR																										
FIRE																										
LAUNCH																										
ATTACK																		.02						.02		
BINGO																										
CANCEL																										
DISTANCE																										
COPY																										
REFUEL																										
REPORT																										
PROCEED																										
LABEL																										
STATION																.02										

	SAVE	SAFE	KIT	KID	LIST	TIME	SPEED	DIVE	DROP	COURSE	PLOT	AIR	FIRE	LAUNCH	ATTACK	BINGO	CANCEL	DISTANCE	COPY	REFUEL	REPORT	PROCEED	LABEL	STATION	"BEEP"
GALF																							.02		
TALE																									
GAME																									.02
CAME	.02																								.04
TIP			.06																						
DIP																									.06
BEAT							.08																		
PEAT							.04																		
GOLD																									.02
COLD																									.06
BARK																									.02
PARK																									
BIG																									
PIG																									
TEN																									
DEN			.02																						
SAP																									
SAT																									
RACE																									
RAZE																									
LAKE																							.02		
LATE																									.02
MAD																									
MAT																									.04
PEAS																									
PLACE																									
SAVE	.92	.08																							
SAFE	.13	.85																						.02	
KIT			.75	.17																					.02
KID			.02	.94																					
LIST					.98																				
TIME						.96		.04																	
SPEED				.02			.96																		
DIVE						.04		.96																	
DROP									1.00																.02
COURSE										1.00															
PLOT											.96														.04
AIR												1.00													
FIRE													.98												.02
LAUNCH														1.00											
ATTACK								.02							.92										.02
BINGO																1.00									
CANCEL																	.98								.02
DISTANCE																		.98							.02
COPY																			1.00						
REFUEL																				1.00					
REPORT																					.98				.02
PROCEED																						1.00			
LABEL																							1.00		
STATION	.02	.02																						.94	

APPENDIX I

CONFUSION MATRIX FOR OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION CTT

The matrix element a_{ij} indicates the proportion of the time that the T600 "thought" that a subject said word j when the subject actually said word i. The last column, annotated "beep", indicates the proportion of the time that the T600 rejected vocabulary word i and "beeped".

Several rows do not sum to exactly 1.00; this is because of inaccuracy in the elements of the row caused by rounding to two decimal places.

	GALE	TALE	GAME	CAME	TIP	DIP	BEAT	PEAT	GOLD	COLD	BARK	PARK	BIG	PIG	TEN	DEN	SAP	SAT	RACE	RAZE	LAKE	LATE	MAD	MAT	PEAS	PEACE	SAVE	SAFE	KIT	KID	LIST	TIME	SPEED	DIVE	DROP	COURSE	PLOT	AIR	FIRE	LAUNCH	ATTACK	BINGO	CANCEL	DISTANCE	COPY	REFUEL	REPORT	PROCEED	LABEL	STATION	"BEEP"
GALE	.87	.13																																																	
TALE	.08	.92																																																	
GAME			.85	.13											.02																																				
CAME			.17	.75											.02	.02											.02	.02																							
TIP		.02			.46	.35									.02														.06									.02													.06
DIP					.17	.67										.02													.02																						.13
BEAT			.02				.70	.13																	.04	.04							.06																		
PEAT							.27	.60																	.08	.02																									.02
GOLD									.81	.17																																									.02
COLD									.25	.73																																									.02
BARK											.71	.21																									.02		.04												.02
PARK											.25	.71																											.02												.02
BIG													.75	.21		.02					.02																														
PIG													.25	.73	.02																																				
TEN					.02										.77	.15												.02		.04																					
DEN		.02				.04								.02	.29	.63																																			
SAP																	.83	.17																																	
SAT																	.04	.96																																	
RACE																			.87	.13																															
RAZE																			.19	.79																															.02
LAKE													.02	.02							.81	.15																													
LATE								.02					.02								.08	.83							.02																						.02
MAD															.04								.85	.04										.06																	
MAT																							.04	.90																	.04										.02
PEAS								.04																	.85	.21																									
PEACE																										1.00																									
SAVE																											.90	.10																							
SAFE																											.21	.73																						.04	
KIT					.02	.02		.02								.02													.80	.10																					.02
KID														.02		.04													.06	.88																					
LIST																															1.00																				
TIME																																.96		.02					.02												
SPEED								.04																				.02					.94																		
DIVE																																.06		.92																	.02
DROP																																			.98																[illegible]
COURSE																															.02					.94															.04
PLOT											.02																										.94			.02											.02
AIR																																						1.00													
FIRE																																							1.00												
LAUNCH																																			.02					.94											.04
ATTACK															.02	.04		.02					.02	.02																	.85										.02
BINGO																																										1.00									
CANCEL																																											.98								[illegible]
DISTANCE																																												.98							[illegible]
COPY																																													.98						[illegible]
REFUEL													.02																																	.94					.04
REPORT																																															.98				[illegible]
PROCEED																																																1.00			
LABEL																					.02																												.98		
STATION																												.10																						.88	[illegible]

APPENDIX J

CONFUSION MATRIX FOR OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION STT

The matrix element a_{ij} indicates the proportion of the time that the T600 "thought" that a subject said word j when the subject actually said word i. The last column, annotated "beep", indicates the proportion of the time that the T600 rejected vocabulary word i and "beeped".

Several rows do not sum to exactly 1.00; this is because of inaccuracy in the elements of the row caused by rounding to two decimal places.

	CALL	TALL	GAME	CAME	TIP	DIP	BEAT	PEAT	GOLD	COLD	BARK	PARK	BIG	PIG	TEN	DEN	SAP
CALL	.87	.13															
TALL	.02	.98															
GAME	.02		.77	.19												.02	
CAME			.35	.56												.04	
TIP					.46	.38											
DIP					.15	.64									.02	.02	
BEAT							.65	.19									
PEAT			.02				.23	.54									
GOLD									.81	.13							
COLD									.23	.75							
BARK											.75	.23					
PARK											.17	.81					
BIG													.75	.25			
PIG								.02					.29	.67			
TEN					.02	.02									.77	.19	
DEN															.21	.75	
SAP																	.92
SAT																	.09
RACE																	
RAZE																	
LAKE																	
LATE							.04	.02									
MAD																	
MAT																	
PEAS																	
PEACE																	
SAVE																	
SAFE																	
KIT					.04	.02											
KID														.02		.02	
LIST																	
TIME												.02					
SPEED							.04	.02									
DIVE																	
DROP																	
COURSE																	
PLOT																	
AIR																	
FIRE																	
LAUNCH																	
ATTACK																.04	
BINGO																	
CANCEL																	
DISTANCE																	
COPY																	
REFUEL																	
REPORT												.04					
PROCEED																	
LABEL																	
STATION														[illegible]			

	SAT	RACE	RAZE	LAKE	LATE	MAD	MAT	PEAS	PEACE	SAVE	SAFE	KIT	KID	LIST	TIME	SPEED	DIVE
CALL																	
TALL																	
GAME																	
CAME						.02											
TIP												.06					
DIP												.04					
BEAT								.02	.06							.06	
PEAT								.04	.04							.06	
GOLD																	
COLD																	
BARK																	
PARK																	
BIG																	
PIG													.02				
TEN																	
DEN													.04				
SAP	.08																
SAT	.89										.02						
RACE		.94	.06														
RAZE		.09	.91														
LAKE				.88	.10												
LATE		.04		.19	.71												
MAD						.88	.08										.02
MAT	.02					.08	.88										
PEAS								.83	.17								
PEACE									1.00								
SAVE										.91	.06						
SAFE										.24	.71						
KIT												.65	.20				
KID												.10	.83				
LIST														1.00			
TIME															.86		.10
SPEED											.04					.90	
DIVE															.02		.98
DROP																	
COURSE																	
PLOT																	
AIR																	
FIRE																	
LAUNCH																	
ATTACK						.06	.02								.04		
BINGO																	
CANCEL																	
DISTANCE																	
COPY																	
REFUEL																	
REPORT																	
PROCEED																	
LABEL					.02												
STATION										.02	.08						

	DROP	COURSE	PLOT	AIR	FIRE	LAUNCH	ATTACK	BINGO	CANCEL	DISTANCE	COPY	REFUEL	REPORT	PROCEED	LABEL	STATION	BEEP
CALL																	
TALL																	
GAME																	
CAME																	.02
TIP																	.10
DIP																	.13
BEAT																	.02
PEAT																	.06
GOLD																	.06
COLD																	.04
BARK																	.02
PARK																	.02
BIG																	
PIG																	
TEN																	
DEN																	
SAP																	
SAT																	
RACE																	
RAZE																	
LAKE																	.02
LATE																	.02
MAD																	.02
MAT						.02											
PEAS																	
PEACE																	
SAVE																	.02
SAFE																.04	
KIT					.04				.02								.04
KID																	.02
LIST																	.02
TIME																	
SPEED																	
DIVE																	
DROP	1.00																
COURSE		.98															.02
PLOT			.94			.02											.04
AIR				1.00													
FIRE					1.00												
LAUNCH			.02			.98											
ATTACK							.81										
BINGO								1.00									
CANCEL									1.00								
DISTANCE										.98							.02
COPY											.96						.04
REFUEL												1.00					
REPORT													.92				.04
PROCEED														1.00			
LABEL															.98		
STATION																.88	

APPENDIX K

CONFUSION MATRIX FOR ALL OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITIONS COMBINED

The matrix element a_{ij} indicates the proportion of the time that the T600 "thought" that a subject said word j when the subject actually said word i.[1] The last column, annotated "beep", indicates the proportion of the time that the T600 rejected vocabulary word i and "beeped".

Several rows do not sum to exactly 1.00; this is because of inaccuracy in the elements of the row caused by rounding to two decimal places.

	GALE	TALE	GAME	CAME	TIP	DIP	BEAT	PEAT	GOLD	COLD	BARK	PARK	BIG
GALE	.89	.10											
TALE	.03	.97											
GAME	.01		.79	.16									.01
CAME			.21	.69									
TIP		.01			.51	.33							
DIP					.12	.72							
BEAT			.01				.68	.17					
PEAT			.01				.24	.63					
GOLD									.81	.16			
COLD									.19	.76			
BARK											.73	.23	
PARK											.24	.74	
BIG													.78
PIG				.01				.01					.27
TEN					.02	.01							
DEN		.01				.03							
SAP													
SAT													
RACE													
RAZE													
LAKE													.01
LATE							.01	.03					.01
MAD													
MAT													
PEAS							.01	.02					
PEACE													
SAVE													
SAFE													
KIT					.04	.01		.01					
KID													
LIST													
TIME												.01	
SPEED							.01	.03					
DIVE													
DROP													
COURSE													
PLOT											.01		
AIR													
FIRE													
LAUNCH													
ATTACK													
BINGO													
CANCEL													
DISTANCE													
COPY													
REFUEL													.01
REPORT												.01	
PROCEED													
LABEL													
STATION													

	PIG	TEN	DEN	SAP	SAT	RACE	RAZE	LAKE	LATE	MAD	MAT	PEAS	PEACE
GALE													
TALE													
GAME		.01	.01										
CAME		.03	.03										
TIP		.01											
DIP		.01	.02										
BEAT												.02	.04
PEAT												.04	.02
GOLD													
COLD													
BARK													
PARK													
BIG	.20		.01					.01					
PIG	.70	.01											
TEN		.77	.17										
DEN	.01	.21	.72										
SAP				.88	.12								
SAT				.07	.92								
RACE						.91	.09						
RAZE						.11	.88						
LAKE	.01							.86	.11				
LATE						.01		.10	.81				
MAD		.01								.90	.05		
MAT					.01					.05	.90		
PEAS												.85	.12
PEACE													1.00
SAVE													
SAFE													
KIT			.01										
KID	.02		.03										
LIST						.01							
TIME													
SPEED													
DIVE													
DROP													
COURSE													
PLOT													
AIR													
FIRE													
LAUNCH													
ATTACK		.01	.03		.01					.03	.02		
BINGO													
CANCEL													
DISTANCE													
COPY													
REFUEL													
REPORT													
PROCEED													
LABEL								.91	.01				
STATION	.01		.01										

	SAVE	SAFE	KIT	KID	LIST	TIME	SPEED	DIVE	DROP	COURSE	PLOT	AIR	FIRE
GALE													
TALE													
GAME													
CAME	.01	.01											
TIP			.06									.01	
DIP			.02										
BEAT							.07						
PEAT							.03						
GOLD													
COLD													
BARK											.01		.01
PARK													.01
BIG													
PIG				.01									
TEN		.01		.01									
DEN			.01	.01									
SAP													
SAT		.01											
RACE													
RAZE													
LAKE													
LATE			.01										
MAD								.03					
MAT													
PEAS													
PEACE													
SAVE	.91	.08											
SAFE	.20	.77											
KIT			.73	.15									.01
KID			.06	.88									
LIST					.92								
TIME						.93		.05					.01
SPEED		.03		.01			.93						
DIVE						.04		.92					
DROP									.99				
COURSE					.01					.97			
PLOT											.94		
AIR												1.00	
FIRE													.99
LAUNCH									.01		.01		
ATTACK						.01		.01					
BINGO													
CANCEL													
DISTANCE													
COPY													
REFUEL													
REPORT													
PROCEED													
LABEL													
STATION	.01	.01											

	LAUNCH	ATTACK	BINGO	CANCEL	DISTANCE	COPY	REFUEL	REPORT	PROCEED	LABEL	STATION	"BEEP"
GALE										.01		
TALE												
GAME												.01
CAME												[illegible]
TIP												.02
DIP												.10
BEAT												.01
PEAT												.03
GOLD												.03
COLD												.04
BARK												.02
PARK												.01
BIG												
PIG												
TEN												
DEN												
SAP												
SAT												
RACE												
RAZE												.01
LAKE										.01		.01
LATE												[illegible]
MAD												.03
MAT	.01	.01										.02
PEAS												
PEACE												
SAVE												.01
SAFE											.03	
KIT				.01								.03
KID												.01
LIST												.01
TIME												
SPEED												
DIVE												.01
DROP												.03
COURSE												[illegible]
PLOT	.01											.03
AIR												
FIRE												.01
LAUNCH	.97											.01
ATTACK		.87										.01
BINGO			1.00									
CANCEL				.99								[illegible]
DISTANCE					.98							[illegible]
COPY						.98						[illegible]
REFUEL							.98					[illegible]
REPORT								[illegible]				[illegible]
PROCEED									[illegible]			
LABEL										[illegible]		
STATION											[illegible]	.01

APPENDIX L

T600 RECOGNITION ERRORS*

An entry w/x (y/z) indicates that w recognition errors, of which y were errors of rejection (of vocabulary words), occurred in the first half of the trial and x recognition errors, of which z were errors of rejection (of vocabulary words), occurred during the second half of the trial.

I. TOTAL T600 RECOGNITION ERRORS (I.E., INCLUDING ALL VOCABULARY WORD TYPES)

SUBJECT NUMBER	OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION					
	NTT		CTT		STT	
1	9/10	(0/2)	9/6	(3/0)	9/8	(1/1)
2	6/4	(1/1)	8/10	(2/2)	4/9	(1/1)
3	5/9	(1/3)	8/11	(0/1)	11/10	(2/2)
4	3/4	(0/1)	3/5	(0/0)	4/4	(0/0)
5	8/6	(0/0)	10/12	(0/1)	10/12	(0/1)
6	2/2	(1/0)	2/4	(0/0)	5/3	(0/0)
7	8/8	(1/1)	10/9	(1/0)	12/8	(0/0)
8	4/5	(0/0)	6/7	(1/1)	6/9	(0/0)
9	3/2	(0/0)	6/6	(0/1)	7/7	(0/0)
10	2/0	(0/0)	9/12	(3/1)	4/7	(1/1)
11	7/8	(1/1)	8/12	(0/1)	10/12	(0/2)
12	8/5	(2/1)	12/14	(1/0)	12/11	(4/4)
13	0/2	(0/0)	4/7	(1/2)	3/4	(0/1)
14	5/5	(0/1)	5/9	(0/0)	6/5	(0/1)
15	3/8	(0/1)	2/7	(0/1)	9/8	(6/4)
16	7/8	(0/0)	10/5	(0/0)	8/10	(0/0)
17	6/5	(0/0)	8/5	(1/0)	6/9	(1/2)
18	3/5	(0/0)	3/3	(1/1)	6/0	(1/0)
19	8/6	(0/0)	6/4	(0/0)	7/8	(0/0)
20	4/6	(1/0)	12/10	(2/2)	6/7	(0/0)
21	10/8	(0/0)	8/9	(0/1)	14/10	(0/1)
22	3/3	(0/0)	4/5	(1/0)	2/6	(0/0)
23	6/6	(0/0)	5/7	(0/1)	3/8	(0/0)
24	3/4	(0/1)	3/6	(0/0)	8/5	(1/0)

II. T600 RECOGNITION ERRORS ON RHYMING VOCABULARY WORDS

SUBJECT NUMBER	OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION					
	NTT		CTT		STT	
1	4/8	(0/1)	6/4	(2/0)	5/6	(1/1)
2	4/2	(0/0)	7/8	(1/1)	3/6	(1/1)
3	3/5	(1/2)	3/8	(0/1)	7/7	(1/2)
4	1/3	(0/1)	2/4	(0/0)	2/3	(0/0)
5	4/4	(0/0)	5/6	(0/0)	4/6	(0/0)
6	1/1	(0/0)	1/3	(0/0)	4/3	(0/0)
7	5/6	(0/0)	4/3	(0/0)	8/4	(0/0)
8	3/4	(0/0)	3/3	(1/1)	3/3	(0/0)
9	1/2	(0/0)	5/5	(0/1)	5/3	(0/0)
10	2/0	(0/0)	3/6	(0/0)	3/3	(1/0)
11	6/5	(1/0)	4/7	(0/0)	7/9	(0/1)
12	4/4	(2/1)	7/6	(1/0)	4/7	(2/2)
13	0/2	(0/0)	4/5	(1/1)	2/2	(0/1)
14	5/3	(0/0)	4/8	(0/0)	5/4	(0/0)
15	2/5	(0/0)	1/4	(0/0)	4/5	(2/2)
16	5/4	(0/0)	6/2	(0/0)	5/5	(0/0)
17	4/4	(0/0)	5/4	(0/0)	5/5	(1/2)
18	1/2	(0/0)	2/2	(1/0)	4/0	(0/0)
19	6/4	(0/0)	4/3	(0/0)	3/3	(0/0)
20	2/5	(1/0)	5/6	(0/0)	5/5	(0/0)
21	8/7	(0/0)	6/5	(0/1)	9/5	(0/1)
22	1/3	(0/0)	3/3	(1/0)	2/5	(0/0)
23	3/4	(0/0)	4/4	(0/1)	2/5	(0/0)
24	2/3	(0/0)	3/4	(0/0)	6/2	(1/0)

III. T600 RECOGNITION ERRORS ON NON-RHYMING BUT SIMILAR VOCABULARY WORDS

SUBJECT NUMBER	OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION					
	NTT		CTT		STT	
1	4/2	(0/1)	2/2	(1/0)	2/2	(0/0)
2	1/1	(0/1)	0/0	(0/0)	1/2	(0/0)
3	1/2	(0/0)	3/3	(0/0)	3/1	(0/0)
4	2/1	(0/0)	1/1	(0/0)	2/1	(0/0)
5	4/2	(0/0)	5/5	(0/0)	4/5	(0/0)
6	0/1	(0/0)	1/1	(0/0)	0/0	(0/0)
7	3/1	(1/0)	4/4	(0/0)	4/3	(0/0)
8	1/1	(0/0)	2/3	(0/0)	2/4	(0/0)
9	2/0	(0/0)	1/0	(0/0)	1/4	(0/0)
10	0/0	(0/0)	3/3	(1/0)	1/3	(0/1)
11	0/1	(0/0)	2/2	(0/0)	1/2	(0/0)
12	4/1	(0/0)	4/6	(0/0)	4/2	(0/0)
13	0/0	(0/0)	0/1	(0/0)	0/2	(0/0)
14	0/0	(0/0)	1/1	(0/0)	1/1	(0/1)
15	1/2	(0/0)	1/2	(0/0)	3/3	(2/2)
16	2/4	(0/0)	4/3	(0/0)	3/4	(0/0)
17	1/1	(0/0)	3/1	(1/0)	1/3	(0/0)
18	1/1	(0/0)	0/0	(0/0)	0/0	(0/0)
19	2/2	(0/0)	2/1	(0/0)	4/5	(0/0)
20	2/0	(0/0)	4/2	(0/0)	0/1	(0/0)
21	2/0	(0/0)	1/2	(0/0)	3/2	(0/0)
22	2/0	(0/0)	1/2	(0/0)	0/1	(0/0)
23	2/2	(0/0)	1/3	(0/0)	1/3	(0/0)
24	1/0	(0/0)	0/2	(0/0)	2/2	(0/0)

IV. T600 RECOGNITION ERRORS ON OPERATIONAL VOCABULARY WORDS

SUBJECT NUMBER	OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION					
	NTT		CTT		STT	
1	1/0	(0/0)	1/0	(0/0)	2/0	(0/0)
2	1/1	(1/0)	1/2	(1/1)	0/1	(0/0)
3	1/2	(0/1)	2/0	(0/0)	1/2	(1/0)
4	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
5	0/0	(0/0)	0/1	(0/1)	2/1	(0/0)
6	1/0	(1/0)	0/0	(0/0)	1/0	(0/0)
7	0/1	(0/1)	2/1	(1/0)	0/1	(0/0)
8	0/0	(0/0)	1/1	(0/0)	1/2	(0/0)
9	0/0	(0/0)	0/1	(0/0)	1/0	(0/0)
10	0/0	(0/0)	3/3	(2/1)	0/1	(0/0)
11	1/2	(0/1)	2/3	(0/1)	2/1	(0/1)
12	0/0	(0/0)	1/2	(0/0)	4/2	(2/2)
13	0/0	(0/0)	0/1	(0/1)	1/0	(0/0)
14	0/2	(0/1)	0/0	(0/0)	0/0	(0/0)
15	0/1	(0/1)	0/1	(0/1)	2/0	(2/0)
16	0/0	(0/0)	0/0	(0/0)	0/1	(0/0)
17	1/0	(0/0)	0/0	(0/0)	0/1	(0/0)
18	1/2	(0/0)	1/1	(0/1)	2/0	(1/0)
19	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
20	0/1	(0/0)	3/2	(2/2)	1/1	(0/0)
21	0/1	(0/0)	1/2	(0/0)	2/3	(0/0)
22	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
23	1/0	(0/0)	0/0	(0/0)	0/0	(0/0)
24	0/1	(0/1)	0/0	(0/0)	0/1	(0/0)

* A T600 recognition error was operationally defined in this research to be a failure of the T600 to recognize correctly any vocabulary word which S spoke and includes both incorrect recognition and rejection of vocabulary words; T600 recognition errors do not include those cases where S spoke a word not in the vocabulary (or coughed, sighed, etc.) and the T600 generated a recognition.

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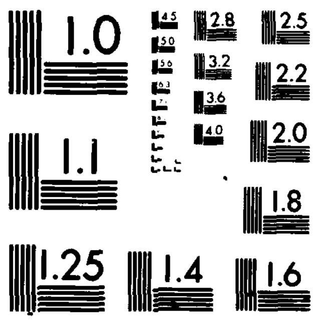

MICROCOPY RESOLUTION TEST CHART
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APPENDIX M

SUBJECT VERBAL ERRORS*

An entry w/x (y/z) indicates that a total of w subject verbal errors, of which y were errors of not speaking any word or speaking a non-vocabulary word (when prompted with a vocabulary word), occurred in the first half of the trial and a total of x subject verbal errors, of which z were errors of not speaking any word or speaking a non-vocabulary word (when prompted with a vocabulary word), occurred in the second half of the trial.

SUBJECT NUMBER	OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION					
	NTT		CTT		STT	
1	2/1	(2/1)	0/1	(0/1)	0/0	(0/0)
2	0/0	(0/0)	1/0	(0/0)	1/2	(1/1)
3	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
4	2/0	(1/0)	0/0	(0/0)	0/0	(0/0)
5	0/1	(0/0)	0/0	(0/0)	2/2	(2/2)
6	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
7	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
8	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
9	0/0	(0/0)	0/0	(0/0)	1/1	(0/0)
10	0/0	(0/0)	0/0	(0/0)	0/1	(0/1)
11	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
12	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
13	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
14	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
15	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
16	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
17	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
18	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
19	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
20	0/0	(0/0)	0/0	(0/0)	0/0	(0/0)
21	0/0	(0/0)	1/0	(1/0)	1/1	(1/1)
22	0/0	(0/0)	0/0	(0/0)	1/0	(1/0)
23	0/0	(0/0)	0/1	(0/1)	0/0	(0/0)
24	0/1	(0/1)	0/0	(0/0)	0/0	(0/0)

* A subject verbal error was defined in this research to be a failure of a subject to repeat correctly the presented vocabulary word. This failure could be either a failure to respond (omission) or responding with a non-vocabulary word or the wrong vocabulary word (commission).

APPENDIX N

TRACKER TIME ON TARGET SCORES (MINUTES:SECONDS)

SUBJECT NUMBER	OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION CTT	STT
1	3:11.79	1:55.12
2	2:17.55	1:05.72
3	1:36.84	1:00.78
4	3:04.01	1:50.91
5	2:45.81	1:13.80
6	4:36.08	1:38.12
7	2:21.80	1:14.84
8	2:50.19	1:37.21
9	1:56.89	1:11.92
10	2:53.08	1:37.68
11	1:38.45	1:31.29
12	2:05.59	0:53.40
13	3:19.62	1:43.38
14	2:39.04	1:20.60
15	2:29.46	1:28.80
16	1:31.63	1:12.48
17	1:49.87	1:15.74
18	2:41.58	1:16.44
19	3:08.55	1:55.33
20	2:43.67	1:32.01
21	2:13.05	1:11.87
22	2:44.39	1:17.70
23	2:23.14	1:14.17
24	1:59.16	1:08.21

APPENDIX O

SUBJECTIVE FATIGUE SCORES*

SUBJECT NUMBER	OPERATOR MOTOR LOADING - EXPERIMENTAL CONDITION NTT	CTT	STT
1	14	18	12
2	12	12	12
3	15	13	13
4	20	17	16
5	16	18	19
6	13	12	13
7	14	14	14
8	15	15	13
9	12	11	11
10	14	14	14
11	13	13	9
12	12	12	12
13	13	12	12
14	12	13	13
15	16	12	14
16	5	9	13
17	13	11	13
18	25	23	25
19	14	12	13
20	18	18	18
21	13	13	15
22	14	14	14
23	15	16	12
24	14	14	11

* Higher scores are associated with lower subjective fatigue and vice versa.

Scores were obtained by multiplying the number of items scored as "better than" by two and adding the number of items scored as "same as", as recommended by those who developed the checklist (Pearson and Byars, 1956).

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